TEACHING MRI PHYSICS: CREATING MEDIA WITH A FOCUS ON THE RADIOLOGY CORE EXAM

by
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Abstract

MRI physics is an important component of radiology training and the American Board of Radiology CORE exam. There is a need for improved learning resources on the topic, but current literature does not provide much information about what types of study materials residents value or creating effective media for teaching MRI physics. This thesis project explores the MRI physics resource needs of radiology residents, creates new media based on the results, and establishes the basis for a future study to test its efficacy.

An online needs assessment survey was created and distributed to current members and recent graduates of the Johns Hopkins diagnostic radiology residency program. Respondents reported that current MRI physics resources were confusing and lacked diagrams and animations. The results indicated that residents desire resources with appealing visuals and simplified details. Questions banks and practice questions were consistently rated as the most helpful resources, but webpages with animations, videos, and webpages with diagrams were also ranked highly.

We created a 10-minute animation introducing the fundamentals of MRI physics, incorporating feedback from the needs assessment. This project aims to fulfill the need for visually appealing MRI physics resources to help residents learn these concepts, and to inform educators and content creators about how to improve the quality of educational materials on the subject. After this project, we have also planned for a follow-up study to evaluate the thesis animation in comparison to other media

modalities, with the goal of evaluating how radiology residents best prefer to study for the CORE exam.

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Introduction

MRI Physics for the Radiology CORE Exam

In their third year of residency training, diagnostic radiology residents must pass the American Board of Radiology CORE exam in order to become board-certified. The exam is scored based on performance in a number of sections divided by organ systems and imaging modalities, as well as a separate section covering radiologic physics. On average, 30% of exam questions are about the underlying physics principles of imaging, and 15% of the physics section is devoted to magnetic resonance imaging (MRI) physics (American Board of Radiology 2018). Examinees must achieve a passing score in the physics section in order to pass the CORE exam as a whole. Despite the importance of physics for radiologists, both to the CORE exam and in daily practice, a survey of radiology program directors and instructors (Bresolin et al. 2008) identified significant gaps in resident physics education including a need for more or better resources. A survey of fourth year radiology residents (Shetty et al. 2015) who took the CORE exam indicated that physics was a difficult topic due to a lack of resources and inadequate teaching, and respondents recommended a strong foundation in physics before reviewing other topics. These studies indicate a need for an increased quality and number of radiology physics resources, yet there is little information regarding the most effective and engaging way to teach this material to radiology residents.

Multimedia for Teaching Science

In contrast to traditional media such as printed material, multimedia has risen to widespread popularity with the advent of the television, computer, and internet in the last few decades. Multimedia has been popular not only for casual entertainment but also for education. Multimedia teaching, specifically use of cartoon-style animations, has been shown to be more effective than conventional lectures in teaching science subjects to secondary school students (Thomas and Israel, 2014). A 2007 summit devoted specifically to the physics education of radiologists spurred the development of web-based education modules in hopes of improving the quality of physics education for radiology residents (Hendee, 2009). Despite support in the literature for use of the multimedia in physics education, there is little data regarding the efficacy of different media modalities within graduate medical education.

Current studies may overall favor non-interactive animations over still images for instruction, but there is a large amount of heterogeneity among studies (Höffler and Leutner 2007). Even though animations have been deemed largely superior to static images in teaching procedural-motor knowledge, static images may suffice for teaching problem-solving or declarative knowledge in many cases; declarative knowledge is knowing what something is, like a fact, whereas procedural-motor knowledge is knowing how to do something, like how to ride a bike. Differences between the studies may be attributed to the cognitive load of animations versus static images, which varies depending on the amount of information presented, the inherent difficulty of the subject, and the spatial ability and prior knowledge of the viewer. Given the complex nature of MRI physics as a subject as well as the advanced education of radiology residents themselves, exploration is warranted to compare whether non-interactive animations have an advantage over still images for teaching MRI physics principles.

Cognitive Theory of Multimedia Learning

The Cognitive Theory of Multimedia Learning is a group of evidence-based principles that have shown that people learn better from words and pictures than words alone (Mayer 2005, 2009). These principles can inform media approaches to teaching concepts such as MRI physics. The Cognitive Theory of Multimedia Learning is based on the following three principles:

i. <u>Dual channel principle:</u> People process information through two separate channels (visual and audio)

ii. <u>Limited capacity principle:</u> The capacity or load of each channel is limited at any one time

iii. <u>Active processing principle:</u> Learning is an active process, and meaningful learning may be attained based on a series of processes including the following:

   a. *Selection*: Choosing relevant information

   b. *Organization*: Sorting information into understandable, discrete representations

   c. *Integration*: Combining representations with prior knowledge

With these principles in mind, learning resources should aim to reduce extraneous details that add cognitive load, to help learners better process information, and to help learners make sense of information. The following table is not an exhaustive list of principles, but they are the primary principles kept in mind when creating and assessing media for this study.

Principle	Description
Multimedia principle	Words and picture are better than words alone
Spatial continuity principle	Text should be placed near relevant image
Temporal continuity principle	Text and image should be presented at the same time
Coherence principle	Extraneous words, sounds, and video should be excluded
Modality principle	Images are better with narration than with on-screen text
Signaling principle	People learn better with highlighted cues
Voice principle	A friendly human voice is better than a machine voice
Personalization principle	A conversational voice is better than a formal voice
Image principle	Learning is better without a speaker's image on the screen

Table 1. *Subset of the Principles of Multimedia Learning (Mayer 2009).*

Of the above principles, the multimedia, spatial continuity, temporal continuity, coherence, and modality principles have been shown to be effective in promoting learning when applied to media involving animations (Mayer and Moreno, 2002). Further explanation of the application of these principles will be detailed in the Materials & Methods section.

Project Objectives

The objectives of this project are as follows:

1. Evaluate the needs of diagnostic radiology residents with regards to current MRI physics resources and the Radiology CORE Exam.
2. Create a piece of media to teach MRI physics based on results of the needs assessment above. Media will be intended for the education of current and future radiology residents at Johns Hopkins University.
3. Design a future study to test the efficacy and learner engagement of the media created in this project.

Materials and Methods

Survey of Existing MRI Physics Resources

A preliminary market survey of existing MRI Physics resources was conducted to inform a subsequent needs assessment and creation of educational media. The names of common study resources for MRI Physics and the Radiology CORE Exam were acquired from Dr. Erin Gomez, an Assistant Professor in the Russell H. Morgan Department of Radiology and Radiological Science at the Johns Hopkins University School of Medicine. Additional resources were found through Google and YouTube with relevant search terms including the following examples: “Introduction to MRI physics,” “Radiology MRI physics,” “Learn radiology MRI physics basics,” “How does MRI work,” and “Nuclear physics basics.”

The market research revealed that current MRI physics resources can be divided into categories including textbooks, practice tests, websites with animations, websites with diagrams, videos, and mobile applications with target audiences ranging from the general public to radiology residents. Characteristics of these resources, such as graphics, appearance, audience, subject, and amount of detail, were noted for each in order to inform the creation of the needs assessment.

In addition to a survey of publicly available resources, content was drawn from a portion of Dr. Erin Gomez’s lecture titled “An Advanced Beginner’s Guide to MRI Artifacts.” Information from this lecture informed and focused the needs assessment as well as the media content created for this project.

Needs Assessment – Study Design

A needs assessment survey was distributed to current Johns Hopkins Diagnostic Radiology residents and recent graduates of the residency program to assess perceptions about currently available learning resources for MRI physics. The study was approved by the Johns Hopkins Medicine Institutional Review Board on January 18, 2021 (IRB00264106).

Participants were recruited via e-mail. The needs assessment was distributed as an anonymized link to a list of current Johns Hopkins Diagnostic Radiology (JHDR) residents and recent graduates of the JHDR program within the last three years. The survey link was active for 11 days, allowing adequate time for responses while respecting the timelines of the thesis project. Two reminder emails were sent during the study period to encourage participation.

The aims of the survey were as follows:

1. Identify whether there is a need for improved MRI physics resources
2. Define the characteristics of high-quality MRI physics resources.
3. Learn which media formats/categories radiology residents deemed helpful for learning MRI physics

The survey was administered through Johns Hopkins Medicine (JHM) Qualtrics. The assessment consisted of 9 questions, 7 of which were either multiple choice or Likert scale questions and 2 of which were optional open-ended questions. Complicated or lengthy questions were omitted in consideration of the time and attention of the radiology residents or fellows. The needs assessment was estimated to take between 5-10 minutes to complete.

Figure 1. *Survey flow of needs assessment questions within Qualtrics.*

Cognitive Theory of Multimedia Learning – Application

Based on the results of our needs assessment, we decided to build an animation describing fundamental principles of MRI physics. Following guidance of the Cognitive Theory of Multimedia Learning (Mayer 2009), we applied the following principles in the creation of the script and animation to improve learner outcome:

1. Multimedia Principle: We chose to present the lesson using video in accordance with the Multimedia Principle, with the hope that narration paired with moving images would improve learning and engagement.
2. Spatial Continuity Principle: Labels and on-screen text were placed near to the object(s) of interest.
3. Temporal Continuity Principle: Objects or images were presented at the same time as the accompanying narration or text. Labels are presented at the same time as the relevant image.
4. Coherence Principle: Unnecessary music or sounds that did not add to the imagery or message of the video were excluded.
5. Modality Principle: Narration accompanied the video rather than purely on-screen text. Only key words were shown on screen.
6. Signaling Principle: Cues, including arrows, highlights, and movement, are included at corresponding times of the narration or text.
7. Voice Principle: Dr. Erin Gomez provided a friendly human voice as narration.

8. Personalization Principle: The tone of the script and narration is conversational rather than formal. Transitions and language are more casual. The narrator spoke in first person and introduced her name in the beginning.
9. Image Principle: Although Dr. Erin Gomez narrated the video, we have omitted her image from the screen.

Script Writing

To simplify the eventual process of testing media on current residents and given the timeline of the thesis project, we decided to focus on the fundamentals of MRI physics. Focusing on the fundamentals is the foundation to any further learning within a subject; presenting the most basic level of information may also help reduce confounding factors when comparing different media formats by limiting the influence of existing knowledge or experience.

The script was primarily created by Dr. Erin Gomez based on the content of her PowerPoint lecture titled "An Advanced Beginner's Guide to MRI Artifacts." The language of the script was written to be conversational in nature, which is in line with the voice and personalization principles of the cognitive theory of multimedia learning. The resulting script contained 1,499 words, which equates to roughly ten minutes of narration. The full script can be found in Appendix A.

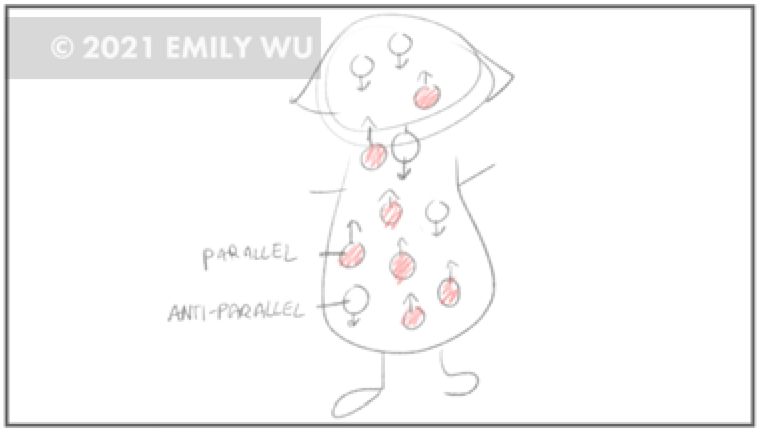
Audio

Narration was recorded with an external RODE VideoMic NTG microphone with multiple takes for editing purposes. Audio was edited in Adobe Audition. Background noise was reduced by capturing a noise print (Effects > Noise

Reduction/Restoration > Capture Noise Print) and noise reduction (Effects > Noise Reduction/Restoration > Noise Reduction (process)). A final version of the narration was created by mixing and matching parts of each take in a multitrack session. Since the resulting volume was too low, the volume was raised through "match loudness" (Window > Match Loudness > Target Loudness set to -19 LUFS).

Storyboarding

The storyboard was created within an InDesign template with sketches pasted from Adobe Photoshop using the lasso tool. Sketches were resized to fit each frame within InDesign. The images were kept as simple sketches to capture the story while the script and a more detailed description of the actions were written below each frame. The storyboard went through several iterations, and the script was updated as needed throughout the process. Feedback on content was primarily provided by Dr. Erin Gomez, Dr. Mahadevappa Mahesh, and Dr. Javad Azadi, who are all faculty of the Russell H. Morgan Department of Radiology and Radiological Science at Johns Hopkins University.



6. When protons are placed within this magnetic field, they'll line up parallel or anti-parallel to the primary magnetic field, with the majority aligning with the direction of the primary magnetic field, just going with the flow.

Video: show multiple H+ in silhouette of patient's body - label/color code as parallel or anti-parallel

Figure 2. *Example of a panel in the storyboard. Full storyboard available in Appendix B.*

Style

We aimed for a lively, friendly style of animation through anthropomorphization and bright, happy colors. Adding anthropomorphic faces and pleasant colors to multimedia have been shown to have a positive effect on learner outcome, enjoyment, and intrinsic motivation (Brom 2018). In our animation, we gave protons and radiofrequency pulses faces and limbs, and the concept of adding faces to protons also received positive feedback from Dr. Erin Gomez and Dr. Mahadevappa Mahesh, who are faculty in the Department of Radiology and Radiological Science at Johns Hopkins University. The overall aim was to increase learner enjoyment and outcome by adding humor and conveying movement in a 3D space, e.g. adding reactive expressions to the protons, emphasizing which direction a proton is spinning, etc.

Asset Creation

Most assets were created in Cinema 4D to facilitate the creation of realistic movement in a 3D space. Assets were exported from Cinema 4D as 16-bit PNG files either as a series of PNG files for animated sequences or a single PNG for objects that did not need to rotate or have moving parts.

To match the cartoon style of the animation, "sketch and toon" settings were used when rendering. Under sketch and toon render settings, only "outline" was selected. Generally, shading was turned off for both background and object when only using an omni light. However, when a directional light was used for some objects, especially non-spherical objects, quantize shading (Render Settings > Sketch and Toon > Shading > Object > Quantize) was employed to reinforce a cartoon style.

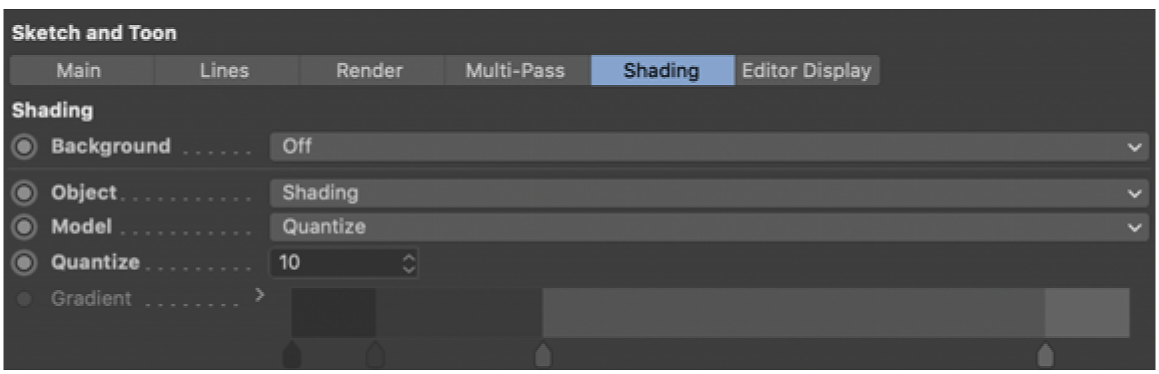


Figure 3. *Cinema 4D sketch and toon render settings for shading (when applicable).*

Assets created in Cinema 4D were made with basic geometric shapes with deformers when possible. For example, the protons were made with a sphere, and the arms were created by applying a bend deformer to a capsule. Some features were made with free form deformers (FFD) to allow for animation; the eyes and mouth on the proton were flattened by applying an FFD and positioning them onto the sphere of the proton. Finally, MoText was used for text which would need to move in a 3D manner such as the “H2O” of the water molecules.

A human character model was created by maneuvering the polygons of editable objects to create the head, body, and arm and leg of one side. Symmetry was applied to the arm and leg to mirror them. The parts of the character model were bridged together, and subdivision surface was applied to smooth the surface. Afterwards, selection, extrusion, rotation, and movement of polygons and loops were used to create details including the clothes and thumbs. Free form deformers were used for manipulations of more irregular shapes such as the character’s face and hair.

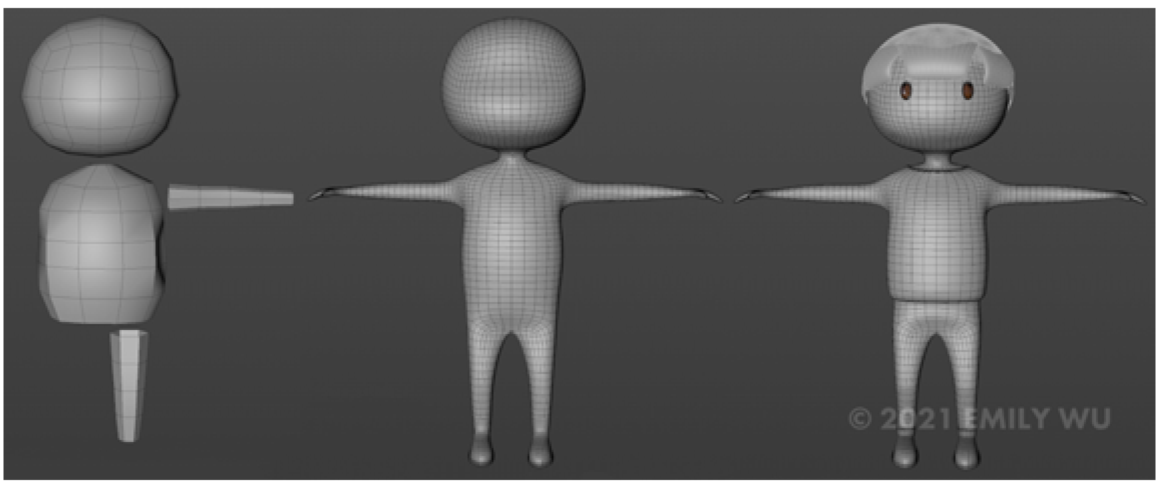


Figure 4. *Sequence of character model creation.*

Finally, to attach certain features to another surface, such as the “H2O” text or the eyes to a sphere, a constraint tag was applied (Tags > Rigging Tags > Constraint). For the “H2O” text, “clamp” was selected to position the text on top of the surface. For the eyes of the protons or character, “parent” was selected after positioning the eyes within the sphere as desired.

Materials and Textures

To customize sketch and toon settings for individual objects, sketch materials were used (Material panel > Create > Materials > New Sketch Material). Within the materials editor, the color and thickness of the outline can be edited. After applying a sketch material to an object, a tag appears which can be clicked to edit how lines are applied; usually, a combination of outline, overlaps, intersections, folds, creases, and/or border are selected and adjusted depending on the desired look.

In addition to sketch materials, a default material was also applied to each object; a default material was created with only "color" and "luminance" activated. Usually, the "color" is a lighter version of the "luminance" color. This was the standard material used for simple and round shapes such as the protons and water droplets in the animation. For shapes that needed to achieve more of a 3D appearance, "reflectance" was used at a lower opacity and brightness. Reflectance was used for objects such as the spinning top or the eyes of the characters. Some small parts, such as the arms and mouth of the proton, did not need any shading, so only "luminance" was activated, and "color" and "reflectance" were deactivated.

Some assets required more complicated materials, such as the human character and muscle. To color the character, standard UV mapping was used by unwrapping the character, editing the exported texture file in Photoshop, and uploading the resulting .PSD file (Material Editor > Color > Texture > Load Image).

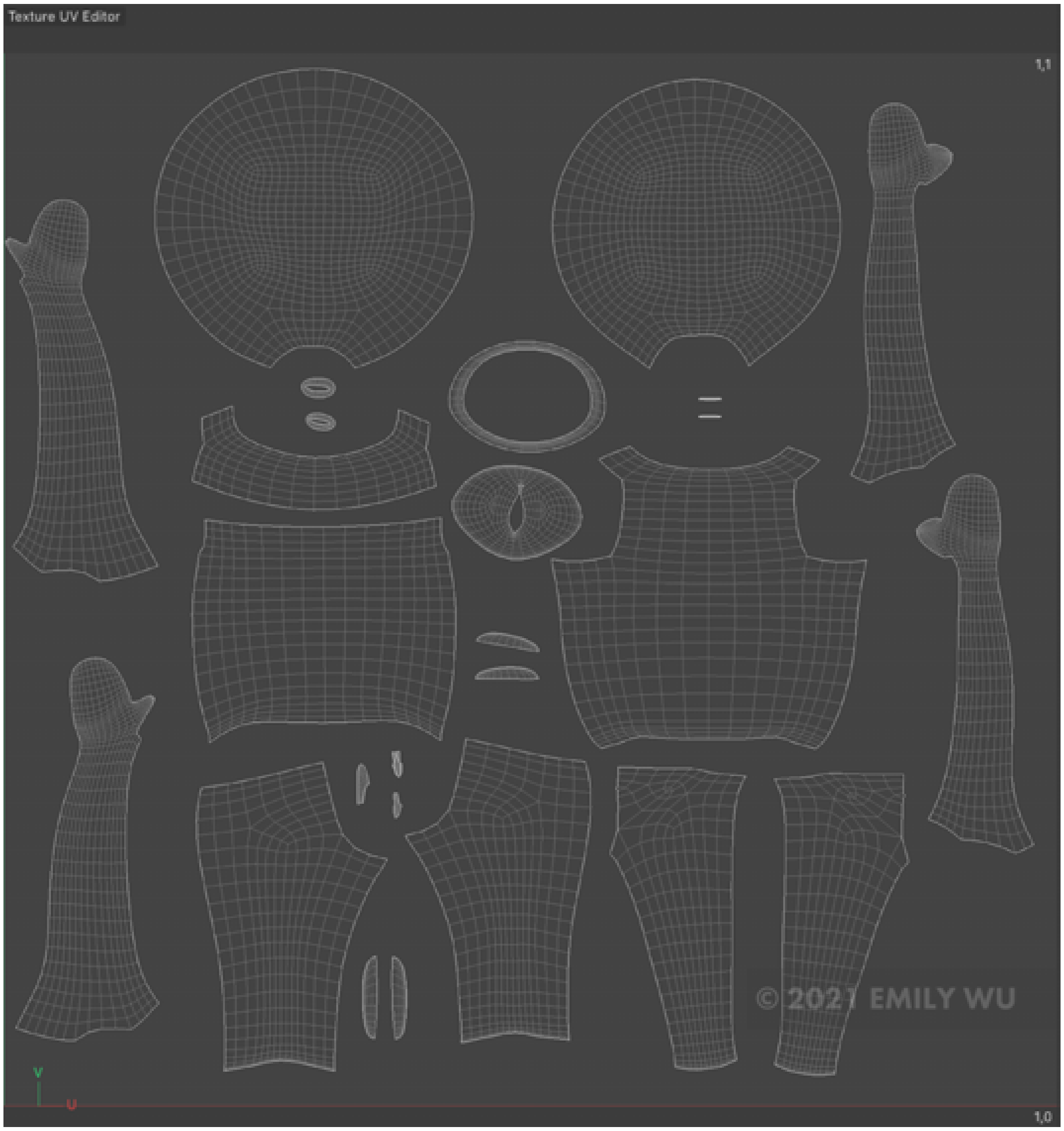


Figure 5. *Unwrapped UVs of character model within Cinema 4D.*

Gradient shading, such as that used for muscle tissue, was achieved using multiple materials and the "select polygons" tool. After a base color was applied to the entire object (muscle), half of the polygons were selected on the editable object with "only select visible elements" off in this case. A new material with a gradient alpha was applied only to the selected polygons. Other objects, such as the MRI scanner, were also colored by selecting polygons on an editable object with “only select visible elements” activated.

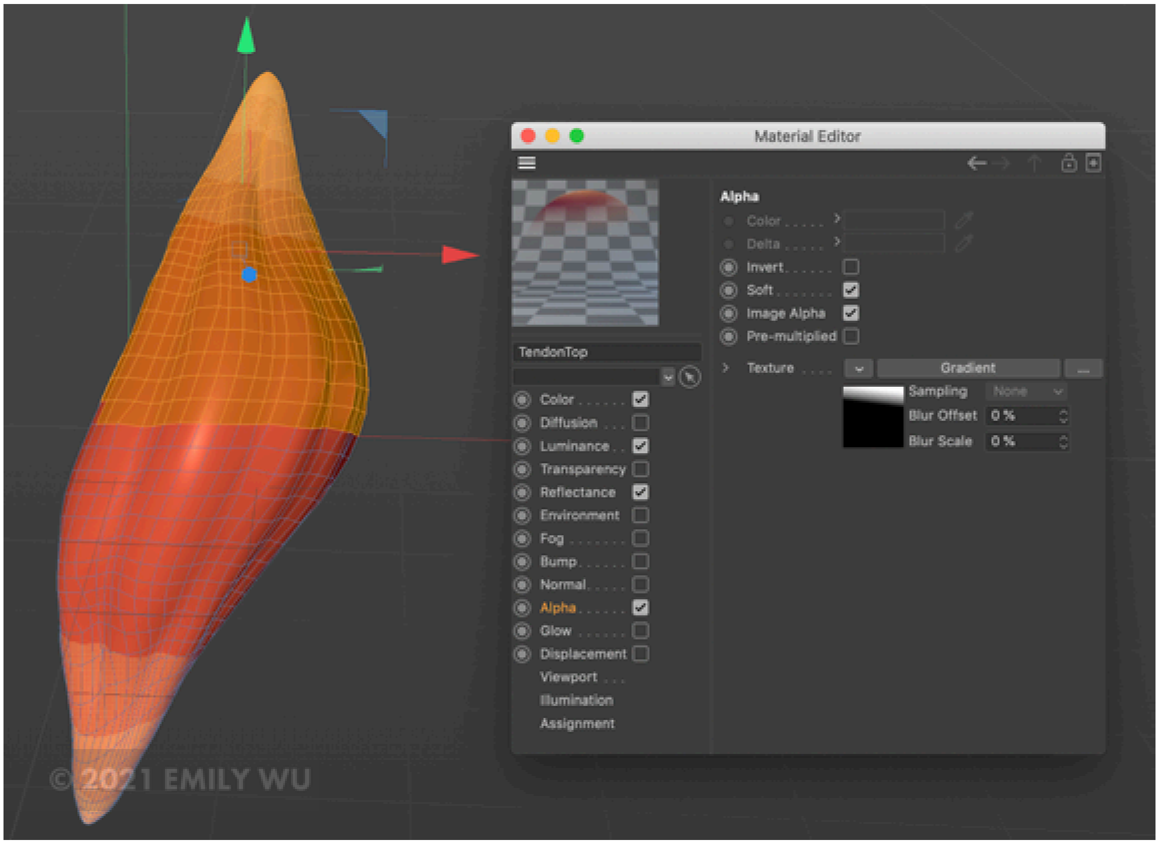


Figure 6. *Gradient coloring of muscle using polygon selection and a gradient alpha. Not all text in figure is intended to be read.*

Animation

Much of the animation in this project, particularly that which involved rotation, was accomplished within Cinema 4D primarily through the use of deformers, including free form deformers (FFD), pose morph, and basic manipulations (position and rotation) of objects. For example, the strength and angle of bend deformers were keyframed to move the arms and legs of protons. For the eyes and mouths of characters, pose morph was applied to their FFDs and was manipulated while in point mode. While the movement of most whole objects was achieved with After Effects, some random movement, such as the floating water molecules and protons, was achieved by applying a vibrate tag with position and rotation enabled at low frequency and amplitude.

Unlike the proton which used bend deformers to simulate movement, the human character was rigged and animated by manually moving controllers (repositioning and rotating “goals” for the chest, neck, head, heels, and wrists). While movement of individual parts of models was achieved within Cinema 4D, gross movement of whole objects was accomplished with After Effects to complement the animation exported from Cinema 4D. For example, the human character as a whole did not change position in Cinema 4D and was moved within After Effects to simulate movement of the entire character.

For the movement of precession, which was an important concept for this project, a basic rotating proton was exported from Cinema 4D. Uniform rotation of the proton was achieved by selecting linear interpolation (Timeline (F-Curve) > Linear Interpolation). After importing the resulting series of images into After Effects as a PNG sequence, precession was simulated by rotating the proton to the left and right, essentially a rocking motion.

Most animation within After Effects was achieved through basic animation techniques, primarily by manipulating position, opacity, scale, and rotation. Track matte and masks were oftentimes used for transitions between scenes. Additionally, the plugin Animation Composer 3 by Mister Horse was used to facilitate text and object transitions. “Transitions - 2D Layer” and “Transitions - Text Layer” were used to create more interesting and dynamic motion.

Besides use of basic effects and transitions, a common technique in this project was animating lines and arrows with a trace path (Windows > Create Nulls From Paths > Trace Path) and “trim paths” (Layer Contents > Add > Trim Paths). The “start” or “end” of “trim paths” was pick whipped to the progress of the trace path to animate on or off the ends of a line. Arrows heads were created either with the pen tool or triangles (Polygon Tool, Shape Layer > Polystar Path, Type set to polygon, Points set to 3.0) and linked to the trace path to simulate a moving arrow. This technique only worked with a path created with the pen tool and not through paths created with the shape tool.

In the case of a line looping around an ellipse, a different method was used. First, a path was created in the shape of an ellipse using the pen tool. Then, instead of simulating movement of the line by pick whipping its “end” to the progress of the trace path, the visible line was animated by adjusting the offset of “trim paths.” The head of the arrow was animated by creating a copy of the line path, making it invisible (opacity set to 0), and then linking the arrow’s head as described above to the trace path of the invisible line path. The “end” of “trim paths” of the invisible line path was still linked to the progress of a trace path as usual. Essentially, there is a visible line (animated with “offset”), an invisible line (animated with “end”), and an arrow head (linked to the invisible line) used to simulate an arrow moving in a loop.

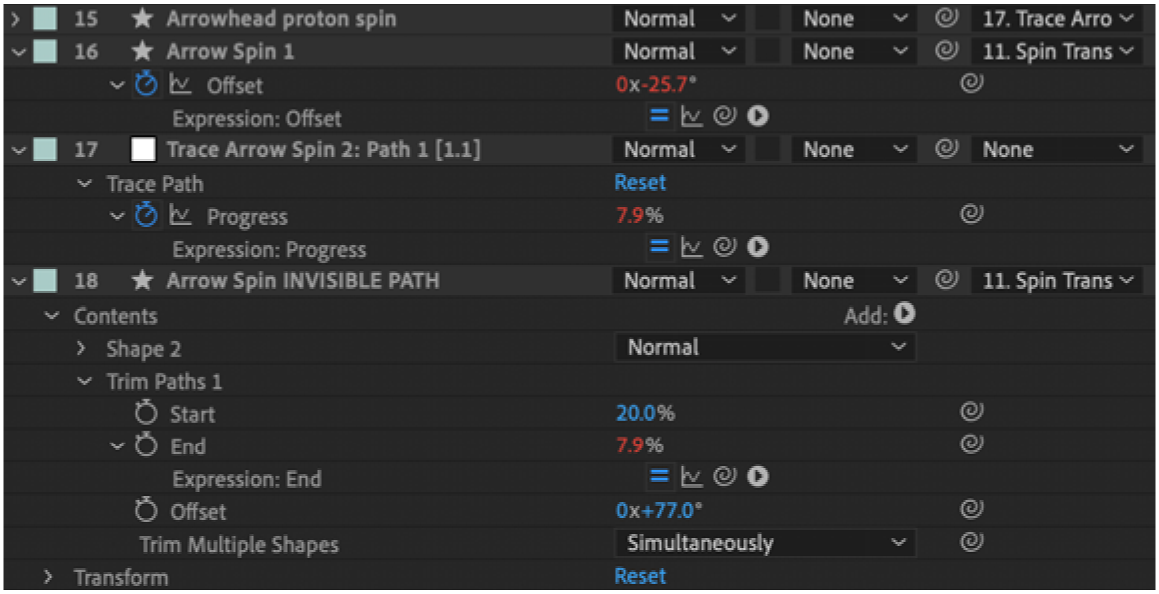


Figure 7. *Example of animating an arrow around a loop within After Effects. "Arrowhead proton spin" (layer 15) is the head of the arrow; note that it is linked to layer 17, which is the trace path of the invisible line path (layer 18). "Arrow spin 1" (layer 16) is the visible line.*

Accessibility

The contrast of important instructional elements and text adhered to Web Content Accessibility Guidelines (WCAG 2.1). The value contrast ratio was maintained at a minimum of 3:1 for large scale text (at least 14pt and bolded or 18pt and larger) and 4.5:1 for regular sized text. Contrast was measured and adjusted using the WebAIM Contrast Checker website.

Results

Needs Assessment – Respondent Year Distribution

Of the 53 residents or recent graduates who were contacted, 52% (28 of 53) completed the needs assessment. Of the 28 respondents, 12 were in clinical practice, and 16 were still in residency training (Figure 8).

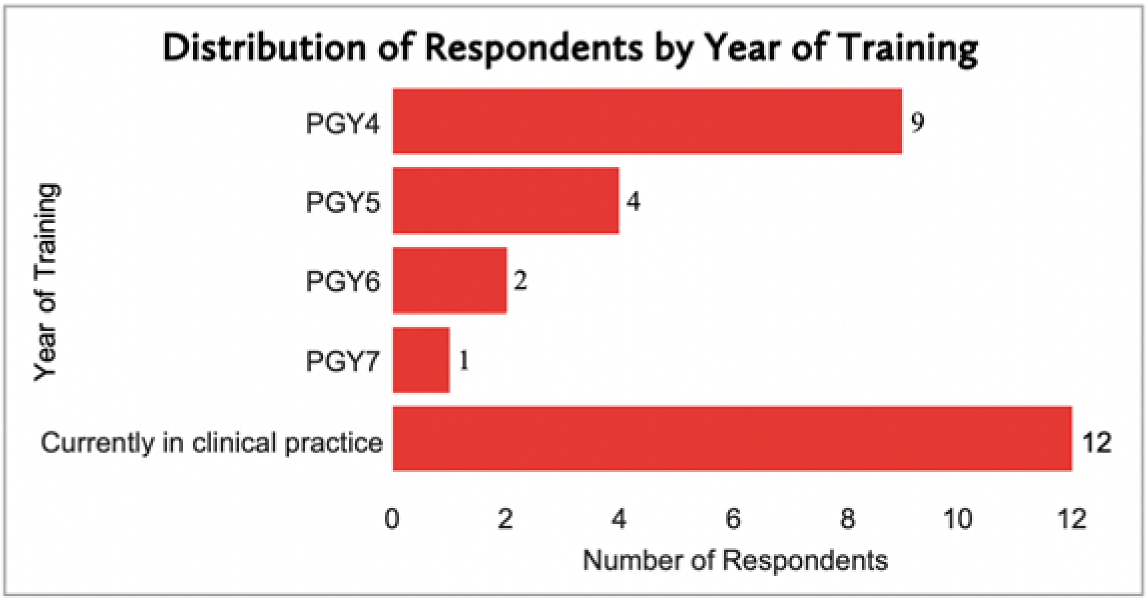


Figure 8. *Distribution of survey respondents by year of training.*

Needs Assessment – General Resource Needs

Participants were asked the question, "Do you feel you have or had adequate MRI physics resources in order to prepare for the Radiology CORE exam?" Twenty-two respondents (79%) reported having adequate physics resources when preparing for the Radiology CORE exam, and six respondents (21%) reported having inadequate resources.

For information more specific to the project, we asked respondents to rate their level of agreement to statements about visuals in MRI physics resources. Most participants either somewhat disagreed (39%) or were neutral (39%) to the statement that current MRI physics resources are visually appealing (Figure 9).

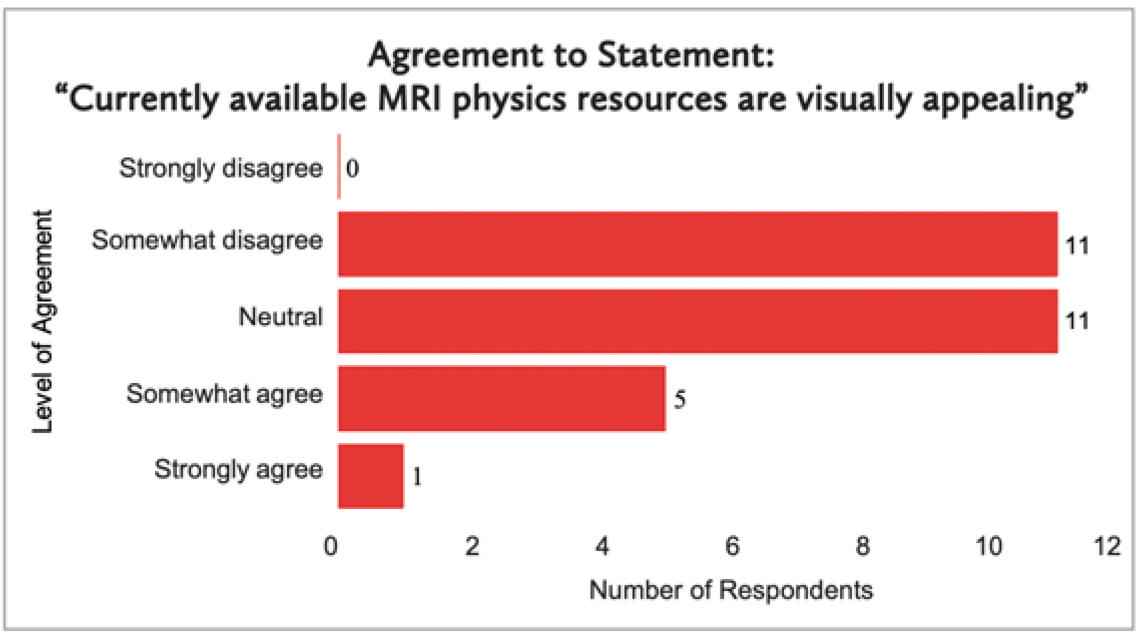


Figure 9. *Levels of agreement to the statement "currently available MRI physics resources are visually appealing."*

Most participants either somewhat agreed (43%) or strongly agreed (46%) that they would benefit from more visuals to explain the fundamentals of MRI physics. Only one respondent disagreed with this statement.

When asked about which MRI physics concepts were the most challenging to learn, the majority of respondents (54%) selected k-space and k-space mapping as the most difficult concept (Figure 10).

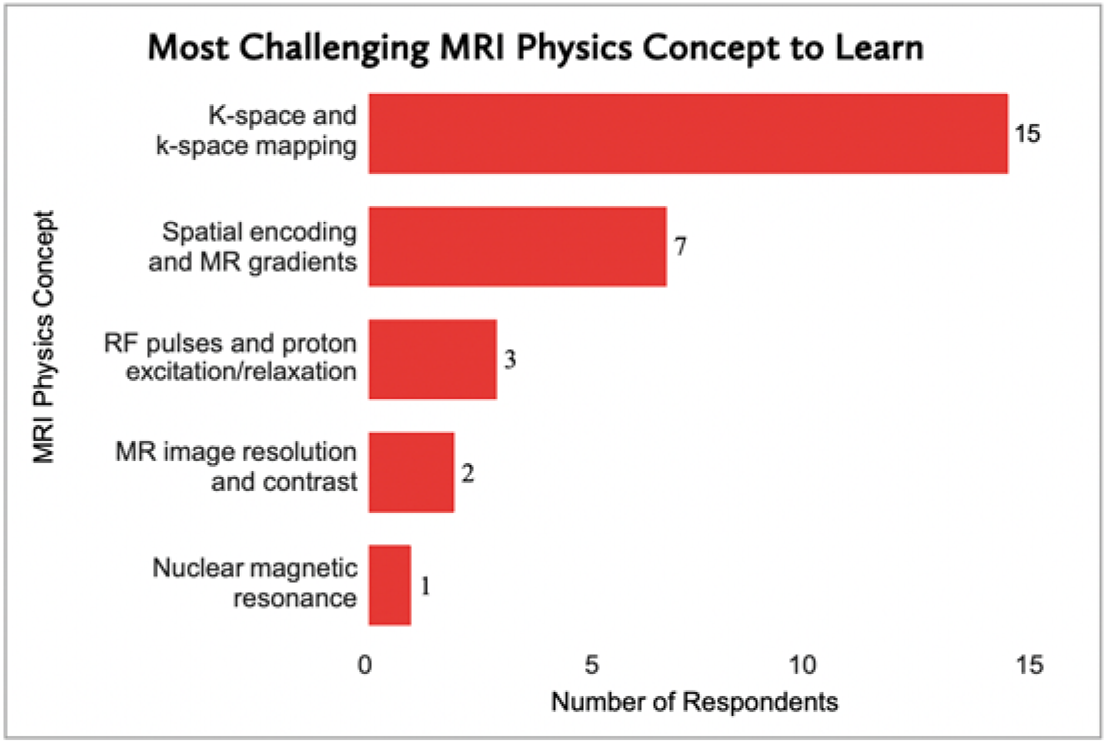


Figure 10. *Participants were asked to select the MRI physics concept that they thought was the most difficult to learn.*

Three participants responded to an optional open response question in which participants may explain why they chose a particular concept as the most challenging, summarized in Table 2.

Free Response Answers (for Figure 10)
Any of the above concepts can be very complicated when considered in depth, the CORE only asks for a basic clinical understanding
Highly abstract concept with high level math
Our brains are not built to understand these subatomic interactions.

Table 2. *Optional free response explanations to the question posed in Figure 10.*

Finally, all 28 participants were asked to write in their favorite resource for studying MRI physics (Table 3). All but one participant named at least one resource.

Free Response: Favorite Resource(s) for Studying MRI Physics
"Introducing MRI" video series by Dr. Michael Lipton (Albert Einstein College of Medicine). Duke Review of MRI Principles. MRI Made Easy (by Hans Schild).
Animations
Core Physics Review
Dr. Michael Lipton videos on YouTube, Introducing MRI series.
Duke review of MR physics
For core, it was core physics review (mostly the online modules)
Huda
MRI made easy
Mri questions. Com
None at the moment
RAM
RAM
RAM Physics
RAM Physics course
RAM/Core Physics
RadCore physics app question bank; Ram physics review course
Radiology simplified/Ram physics (videos & questions)
Ram's course and the CRC physics book

(table continued on next page)

(table continued from previous page)

The Essential Physics of Medical Imaging, Third Edition
The green physics sample questions app
The physics app
War Machine (Prometheus Lionhart), Ram Core physics lectures
War machine
War machine
War machine
War machine and Prometheus videos — but I imagine both will be difficult to use when reviewing material a second time because of length, and you can't click through quickly like a webpage
YouTube Einstein Medicine Lecture Series
catherine westbrook books

Table 3. *Participants' responses to an open-ended question asking for their favorite resource for studying MRI physics.*

The resource mentioned most often was "RAM/Core Physics Review" (10 individuals or 36% of participants). The second most preferred resource was "*Radiologic Physics - War Machine* by Prometheus Lionhart" (5 individuals or 18% of participants).

Needs Assessment – Properties of MRI Physics Resources

To understand more about the current needs of radiology residents related to purpose of creating new educational media, we asked respondents more specific questions about current MRI physics resources. When asked to identify properties that define a good MRI physics resource, a majority reported that a good MRI physics resource contains practice questions (86%), appealing visuals (82%), and/or simplified details (64%), as seen in Figure 11.

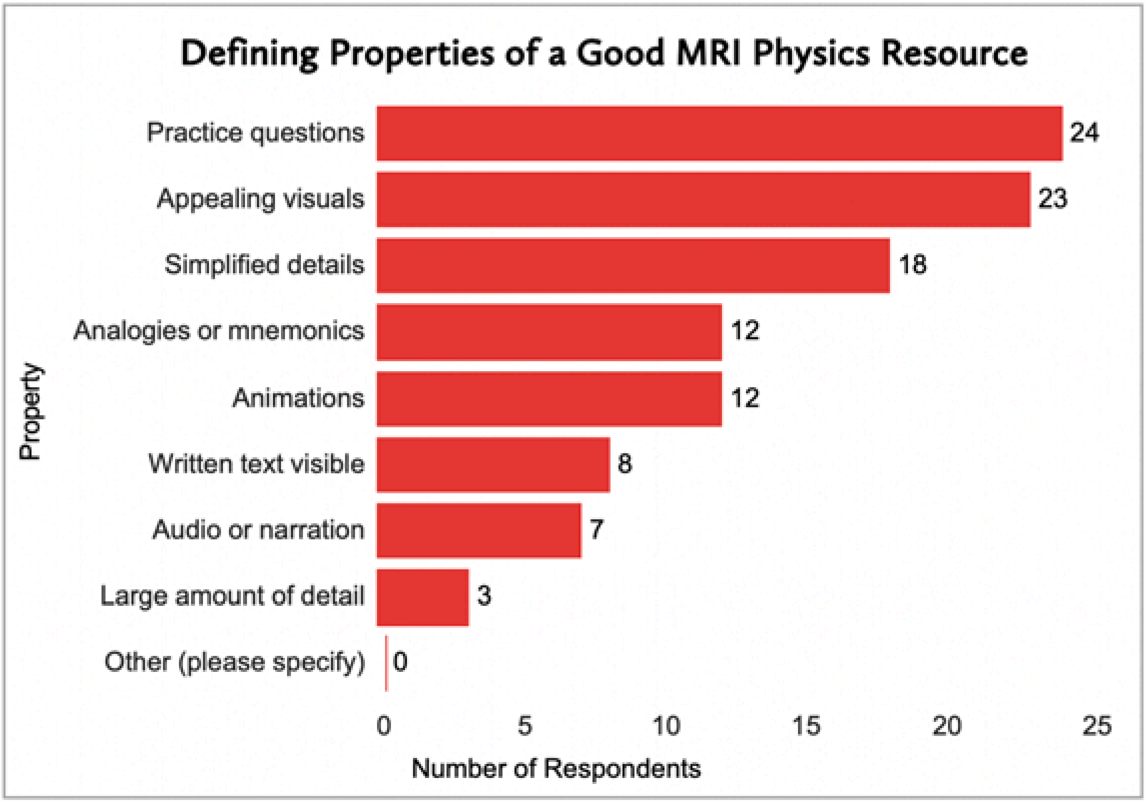


Figure 11. *Respondents were asked to select all properties that defined a good MRI physics resource. The question allowed for multiple selections.*

We also asked residents to identify properties that are lacking in current MRI physics resources. The three most common answers were that resources were confusing (54%), lacked diagrams of animations (43%), and/or were too complex in their explanations (39%). Participants were also allowed to type in their own answers (Table 4).

Free Response Answers: Lacking Qualities of Current Resources
Examples of applicability to clinical practice for each relevant concept/topic
Explanations waver between too simplistic and too complex
Not real life applicable enough
There were no resources which provided enough practice questions to explore the nuances of what was just taught (where is the resources with 50 "homework" questions for each topic?)

Table 4. *Optional free response answers when asked to identify properties which are lacking in current MRI physics resources. Answers were edited only for spelling.*

Finally, participants rated the helpfulness of common educational media for learning MRI physics (Figure 12). Each format was rated using a sliding scale from zero to ten where zero is considered "not helpful at all" and ten is "extremely helpful." The average rating of each format is shown below. The formats perceived as most helpful were "Question banks/practice tests" (average rating 8.04), "Webpages with animations" (average rating 7.20), and "Videos" (average rating 7.12), and "Webpages with diagrams" (average rating 6.91). The formats perceived as least helpful were "Textbooks" (average rating 5.36) and in-person lectures (average rating 5.14).

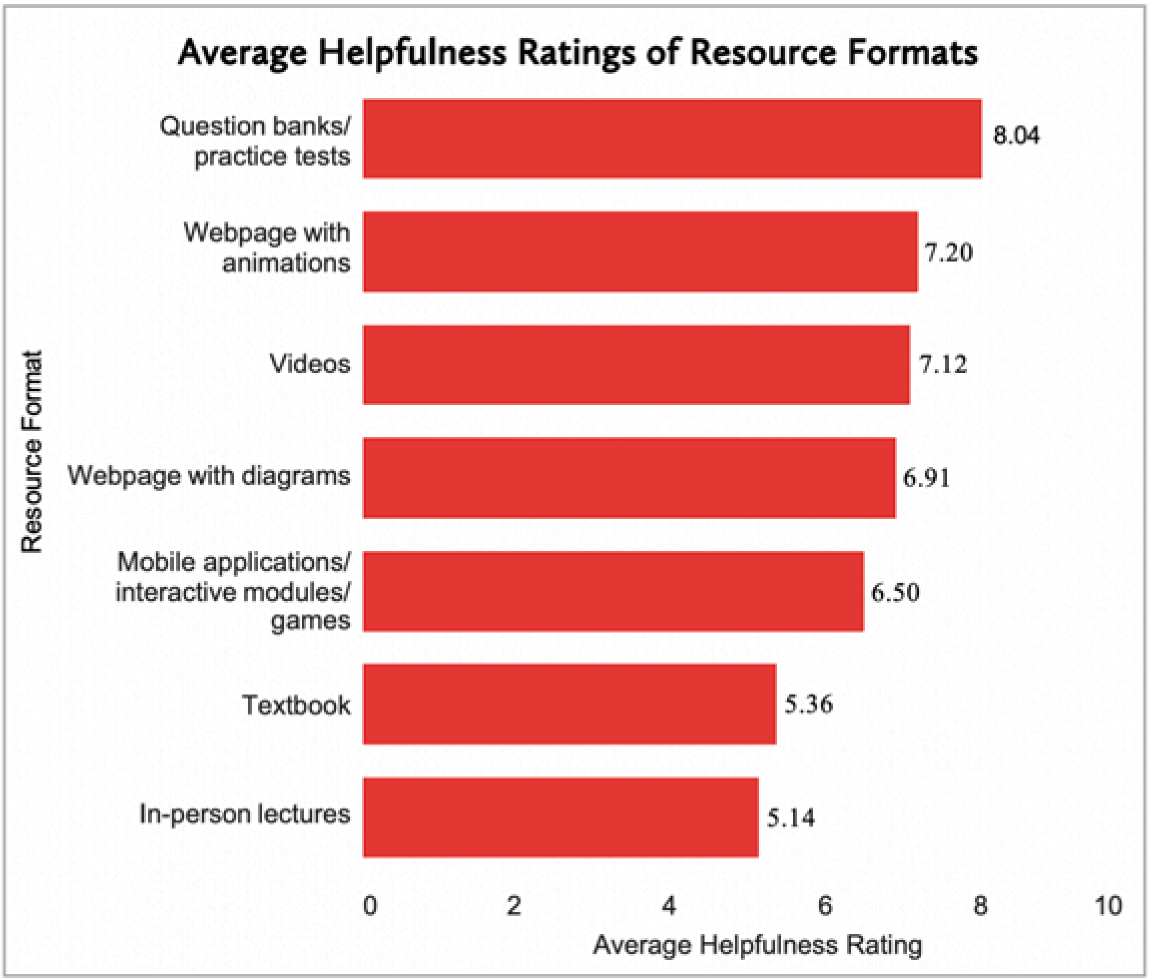


Figure 12. *Average rating of how helpful a resource format was for learning MRI physics.*

Storyboard Stakeholder Feedback

Storyboard feedback given by Dr. Erin Gomez, Dr. Mahadevappa Mahesh, and Dr. Javad Azadi, who are faculty in the Russell H. Morgan Department of Radiology and Radiological Science at Johns Hopkins University School of Medicine, throughout the revision process included the following remarks:

- The faces added to the protons and other anthropomorphized characters can help learners understand how protons are moving in space and facilitate relatable analogies for understanding key concepts.
- Small reactive expressions on the characters' faces may help learner engagement and emphasize the respective characters' roles in the story.
- Have analogies and metaphors treat characters (protons and a radiofrequency pulse) similarly throughout the animation create consistent character roles and reduce confusion.
- Certain concepts should be simplified for an introductory animation. For example, a 90 degree pulse refers to the idea that the net magnetization vector, not individual protons, changes by 90 degrees. However, we show protons knocked down by 90 degrees instead of 180 degrees to reinforce the idea that it is the result of a 90 degree pulse as opposed to a 180 degree pulse, prioritizing major concepts over minutiae.
- A diagram at the end of the animation reviewing the overall sequence was suggested to relate key events and summarize the important takeaways of the animation.

Animation

The final animation of this project was 10 minutes and 23 seconds long.

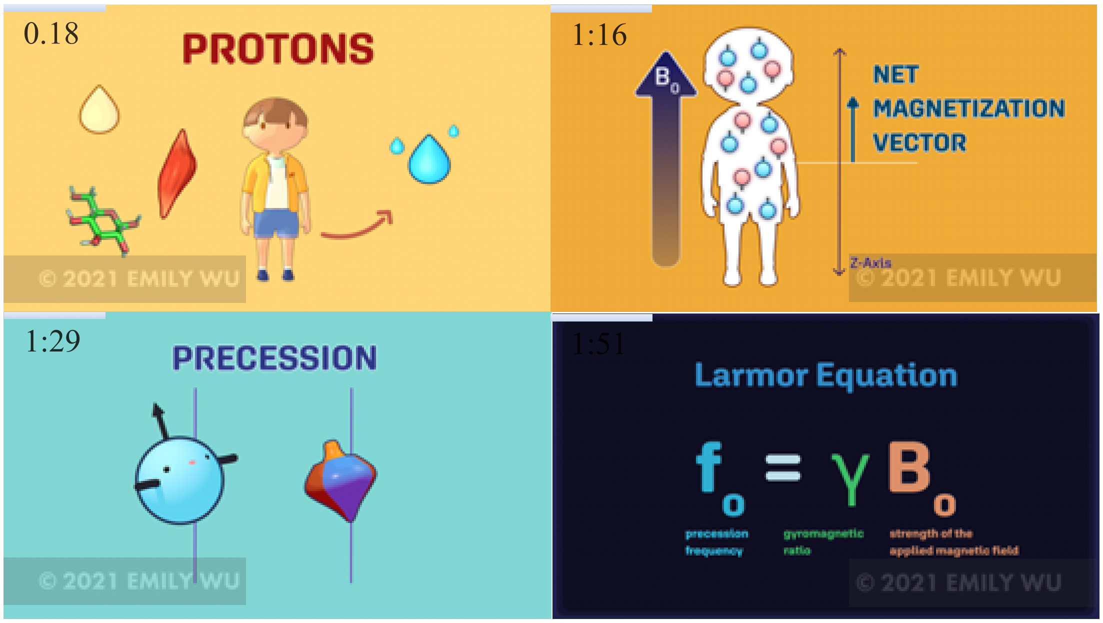


Figure 13. *Stills taken from final animation at shown timestamps. Not all text in figure is intended to be read.*

Access to Assets Resulting from this Thesis

The final animation resulting from this thesis project can be found on the author's student page at https://medicalart.johnshopkins.edu/emily-wu/. The author of this project can also be reached through the Johns Hopkins University School of Medicine Department of Art as Applied to Medicine at the above website (https://medicalart.johnshopkins.edu/).

Discussion

Need for Improved Media for MRI Physics Education

The needs assessment revealed a desire for more high-quality, digestible, and visually appealing multimedia in MRI physics education resources for radiology residents.

While 79% of participants felt that they had adequate MRI physics resources for CORE exam preparation, the majority of residents (89%) reported that they would benefit from having more visuals for learning MRI physics. Additionally, nearly twice as many respondents (11) disagreed with the statement that "currently available MRI physics resources are visually appealing" than those who agreed (6). Finally, 82% of respondents selected "appealing visuals" as a defining property of a good MRI physics resource. Our results suggest that creating more visually appealing media has the potential to improve MRI physics education for radiology residents, which is concordant with other studies (Bresolin et al. 2008; Shetty et al. 2015).

Needs Assessment – Informing Media Creation

Over average, the respondents rated question banks and practice tests highest for helpfulness (average rating 8.04 out of 10). However, highly visual media was also important to residents preparing for the CORE exam as evidenced by the next three highest rated categories: webpages with animations (average rating 7.20 out of 10), videos (average rating 7.12 out of 10), and webpages with diagrams (average rating 6.91 out of 10). This finding is consistent with past studies that have demonstrated the potential of multimedia in improving learner outcome (Höffler 2007; Mayer 2005, 2009;

Thomas and Israel, 2014). Based on the data above, we concluded that a video would well suit our project objectives, which included creating an effective teaching resource and designing a future study to test its efficacy. A video would be able to embody properties that residents identified as defining a good MRI physics resource, including appealing visuals, simplified details, analogies, and animation. Additionally, assets used to create a video could be reused to create other testable media for a follow-up comparison study.

The needs assessment not only influenced which media format we decided to create but also informed our stylistic choices. We aimed for a clean, clear, uncomplicated, and visually appealing style based on respondent preferences (Figure 11) and complaints that currently available MRI physics resources are confusing, lack diagrams and animations, and are too complex. From the script to the visual assets, we eliminated unnecessarily nuanced information and focused on important fundamental concepts. This is reflected in our language, which avoids minutiae and jargon and employs relatable analogies. Our visual style used clean, bold lines and limited extraneous details; this is exemplified through our decision to use sketch and toon rendering in Cinema 4D.

Our diagrammatic and simplified style is intended to decrease cognitive load by avoiding unnecessary details (Mayer 2005, 2009). The style choice is also supported by past studies that favor more schematic and less realistic animations, holding sufficient levels of complexity while reducing extraneous information (Höffler 2007; Milheim 1993; Tversky, Morrison, and Bétrancourt 2002).

Limitations

Our needs assessment may be limited in its applicability to the target population of all radiology residents. Our sample only included residents and recent graduates of the Johns Hopkins Radiology Residency Program, which is a highly selective program ranked as a top radiology program (U.S. News & World Report 2020) and has won multiple Aunt Minnie awards for Best Radiology Training Program (Casey 2015). Given the potential difference in training experience, results of our needs assessment may or may not be generalizable to all radiology training programs at large.

Additionally, our sample size was limited at 28 respondents, and self-selection bias could exist if the volunteers shared a common trait not found in all residents. Finally, our results and conclusions may have limited applicability to subjects outside of MRI physics or for those who are not preparing for the American Board of Radiology CORE exam. Our needs assessment solely focused on MRI physics resources used to prepare for the CORE exam.

Media Creation

We chose to teach the most basic fundamentals necessary to learn MRI physics when beginning the media creation process. The fundamentals form the foundation for understanding more complex ideas, and the resulting media would be more accessible to not only residents learning MRI physics but also a larger general audience. Focusing on a fundamental topic also makes the resulting media more testable since topics that are too advanced or complex may be difficult for participants to learn during a short survey or may favor more highly trained participants.

After we established our topic and media, we worked to iteratively develop analogies and visual metaphors in the script and storyboard. For example, our initial script compared protons to small children, and our anthropomorphic treatment of key characters, such as the protons and radiofrequency pulse, grew as we further developed these analogies. In this case, the radiofrequency pulse was initially drawn as a circle wearing a hat labeled "RF" to differentiate it from the protons who had a similar appearance. Through feedback between team members, the radiofrequency pulse eventually turned into a lightning bolt character with a rough mustache to give it an "energy" feeling and to further distinguish it from the proton characters. The creation of the characters and analogies was a collective and iterative process.

For the timeframe of this thesis project, the needs assessment and ten-minute animation were completed. We have also planned a formal evaluation of the animation along with other testable media using the same assets and a study comparing their efficacy and learner engagement, for which IRB approval was granted on March 9, 2021 (IRB00279436). This study will occur after the thesis period.

The resulting media will be accessible for students on the Johns Hopkins Team Rads website (TeamRads.com) as well as on YouTube.

Future Study Design

We have designed a future study that will compare three media types to gauge resident preferences when studying for the radiology CORE exam. We will compare video, text with animations, and text with static images. The thesis animation will be used to create the testable assets listed above. Our study design involves a Qualtrics survey that includes pre- and post-tests to measure learning, a survey to measure engagement, and a timing feature to measure learning efficiency. This study will inform instructors and content designers on the efficacy of media presentation styles when teaching MRI physics to residents studying for the CORE exam. The results of this study could also be more broadly applied to how science is taught in general.

This future study has been approved by the Johns Hopkins Medicine Institutional Review Board on March 9, 2021 (IRB00279436).

Conclusion

Current MRI physics resources for radiology residents preparing for the CORE exam are lacking in quality visual media. Our needs assessment demonstrated a desire for more engaging MRI physics resources, especially media that is visually appealing, has simplified details, and contains diagrams or animations. Current literature and feedback from radiology residents informed the creation of an animation focusing on the fundamentals of MRI physics.

Planning an animation was iterative and collaborative, from the script to the storyboard. We incorporated both the needs assessment results and principles of the Cognitive Theory of Multimedia Learning into our planning and animation process. In doing so, we focused on avoiding overcomplication in both script content and animation style. As a result, we created a visually appealing animation through bold lines, bright colors, fun characters, and relatable analogies.

The media created as a result of this project aims to help radiology residents learn MRI physics for the radiology CORE exam, a notoriously challenging examination that must be passed in order to achieve board certification. We have planned a follow-up study to evaluate how residents prefer to study from different media modalities. We will use assets created from the thesis animation to create different testable categories to better understand what is most helpful to residents studying for the CORE exam. The MRI physics resource we created during this project will also be freely available online for use by radiology residents and medical students around the country and may serve as the basis for development of additional educational radiology physics modules in the future.

APPENDIX A: Script

Let's talk about protons. We have protons in the fat, muscle, and sugars within our body, and the biggest component is within water. Remember that a significant portion of our bodies consists of water, and that a hydrogen atom is just a proton (one positron and one electron) with a positive and a negative pole. Because of this, each of these protons is capable of acting like a bar magnet. Usually the orientation of these protons is random, but they can be *influenced* by an external magnetic field.

At the most basic level, **an MRI scanner is a giant magnet** and generates its own magnetic field, Bo. When protons are placed within this magnetic field, they'll line up parallel or anti-parallel to the primary magnetic field, with a small majority aligning with the direction of the primary magnetic field, just going with the flow. This generates what is referred to as the **Net Magnetization Vector.** We can imagine this net magnetization along the Z axis (the long axis or length) of the patient's body.
In addition to aligning with the magnetic field produced by the MRI scanner, the protons on your body are also spinning along their axes like little tops or globes - this is called **precession** or **nuclear spin.** The speed or frequency of this axial spin depends on the strength of the applied magnetic field, and can be expressed by the **Larmor equation:** $fo = \gamma Bo$

Simply put, this equation states that the precession frequency of a particle is equal to the strength of the magnetic field applied (Bo) and the gyromagnetic ratio, which is a constant that is unique to each specific nucleus or element.

With the protons aligned with the main magnetic field, we can influence them using externally applied **Radiofrequency (RF)** pulses. When this happens, the protons are knocked down into an alternate plane and also precess together, in phase. The angle depends on the strength and duration of the RF pulse.

“Knocking the protons down” into another plane is a change in the **longitudinal** magnetization. Normally, the majority of protons are “going with the flow” and following the direction of the external magnetic field - but with a little extra energy (**excitation**), protons have the ability to go against the current and instead orient themselves in the opposite direction, against that of the magnetic field (**anti-parallel)**. That’s not all that happens - with some energy applied in the form of the RF pulse, the protons will also precess together, in phase - we can think of this brief synchronization as the **transverse** magnetization of the protons.

To recap, we’ve put some energy into the system and temporarily convinced each of these protons to sit down and get it together. This doesn’t last long - much as if you were knocked off of your feet, or if I yelled at my wild little children as they ran haphazardly around their playroom - recovery is imminent. They’ll behave for a short time, but they'll soon return my energy back to me as the baseline state of disorder is restored. Much like my children, the protons will recover, or return to their original state of orientation with the magnetic field and asynchronous precession.

Now that we’ve gone over what can happen when we administer an RF pulse, let’s talk specifically about what happens during a typical **spin echo sequence.**

Remember, the “flip angle” induced by an RF pulse depends on the strength and duration of the pulse. The thing being “flipped” is the **net magnetization vector.** At the beginning of a standard spin echo sequence, we apply a 90 degree pulse - this means that after the RF pulse has been applied, the net magnetization vector is perpendicular to its original orientation. This orientation is achieved by eliminating longitudinal magnetization and generating a transverse magnetization vector by synchronizing proton precession. During recovery, longitudinal magnetization increases and transverse magnetization decreases (protons dephase) - this looks like a spiraling of the net magnetic vector along the z axis. This spiraling of the net magnetization vector induces an electrical signal by a process called **free induction decay**, which is really just a throwback to the high school physics principle of inducing a current by rotating a magnetic field (search the depths of your mind for the “right hand rule”).

A few additional terms to note: the recovery of the **longitudinal magnetization** of a proton occurs exponentially. The point at which 63% of the longitudinal magnetization has been recovered is called the **T1 time**. The time at which 63% of the **transverse magnetization** has been lost is called the **T2 time.** The T1 and T2 time is unique to each tissue type imaged (think about a class of children running a foot race - each will recover to their baseline heart rate at a slightly different time depending on their physical fitness). We can take advantage of these unique tissue properties and alter the MRI sequences to highlight them - this is called **weighting** and discussion of this is for another time.

That wasn't so bad, was it? Seem too good to be true? In a way, it is. There are a few caveats and drawbacks to the concept of free induction decay:

1. It only applies to 90 degree pulses
2. The signal decays very rapidly - and requires a very fast scanner to detect
3. The dephasing of protons occurs at a speed known as the **T2* constant** - this exponential decay in the synchronization of proton spins is due to the fact that each proton experiences the magnetic field at a slightly different strength, meaning there is never true uniformity in precession - these differences in precession end up compiling, leading to increasingly asynchronous spins. Because each proton already experiences the magnetic field differently than its neighbors, any inhomogeneity in the magnetic field makes dephasing (and thus signal dropout) even worse. These are called **T2* effects**. We can liken T2* effects to distractions in a child's environment.

T2* effects seem terrible! Isn't there any way to fight them? Fret not - the answer is yes. The good news is that we can combat T2* effects and their resulting signal decay with the additional of **another RF pulse**. To understand this, we must remember that although magnetic field inhomogeneity is inconvenient, it is manageable in the sense that the differences in precession speed that they cause are fixed and predictable. As some protons lag behind their faster counterparts, we can apply a **180 degree "refocusing" RF pulse** that instructs them all to turn around and precess in the opposite direction. Much like the classic tale of the tortoise and the hare, though the tortoise is far behind the rabbit, if we ask them both to turn around and head back to the starting line of the race, they will catch up to each other and arrive at the same time due to the differences in their speeds. The crowd goes wild - it's a tie! When the proton precession syncs up following the 180 degree RF pulse, more energy is released back into the system - this is called an **echo,** and it is the information collected by the MR scanner which will eventually generate a medical image**.**

We can liken the 180 degree refocusing pulse and the synchronous precession it creates as an elementary school class photo shoot. The teacher may need to raise her voice in order to get the class to focus its attention on the photographer and achieve a yearbook-worthy shot (the echo). We can apply additional 180 degree pulses to achieve multiple echoes (photo after photo after photo) to continue decreasing the T2* effects. Eventually, however, the students have nothing left to give - less and less energy is yielded back with each echo. Eventually, dephasing occurs completely, and the echo dies out. Once that happens, the sequence must be restarted again with another 90 degree pulse. Imaging in this manner is called **Spin Echo** or **Fast Spin Echo** imaging.

We can use universal diagrams to depict what happens with specific MR sequences. Let's use one recap the basic fast spin echo sequence that we've discussed:

- Protons are aligned with the main magnetic field, Bo and precessing randomly
- A 90 degree RF pulse is applied, eliminating longitudinal magnetization and producing a transverse magnetization vector as protons precess in phase
- Longitudinal recovery and transverse decay occur, producing a signal via free induction decay, which is susceptible to T2* effects

- A 180 degree refocusing pulse temporarily rephases proton precession, producing an echo which can be “read-out” by the MR scanner. The moment that the echo is produced is called the **TE,** or **time to echo.**
- We can apply multiple refocusing pulses in an attempt to capture as many echoes as possible. The echoes become successively weaker until the signal dies out completely and the sequence must be restarted. The time between the repetition of sequences is called the **TR,** or **time to repetition.**

APPENDIX B: Storyboard

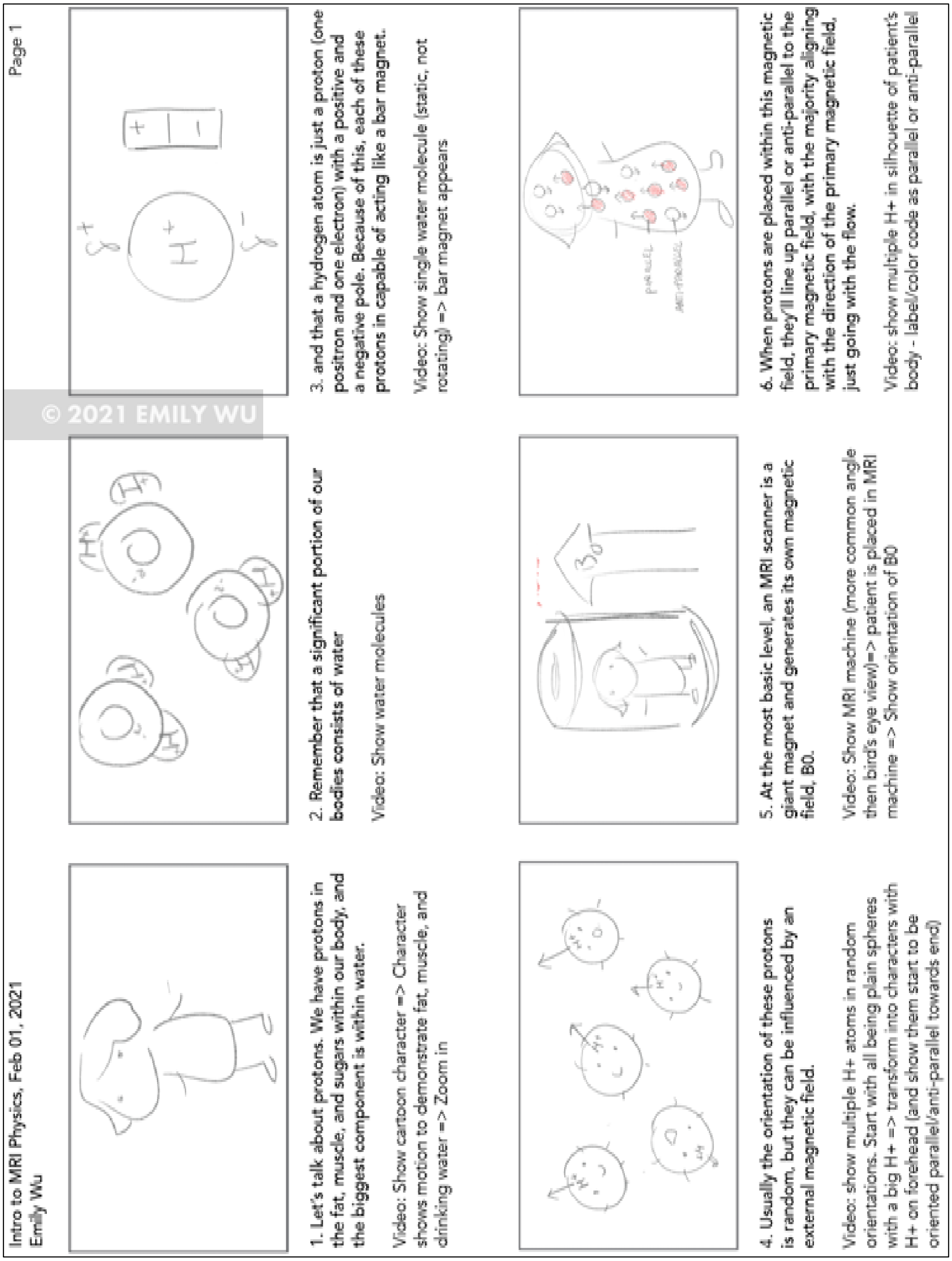


Figure 14. *Storyboard, page 1.*

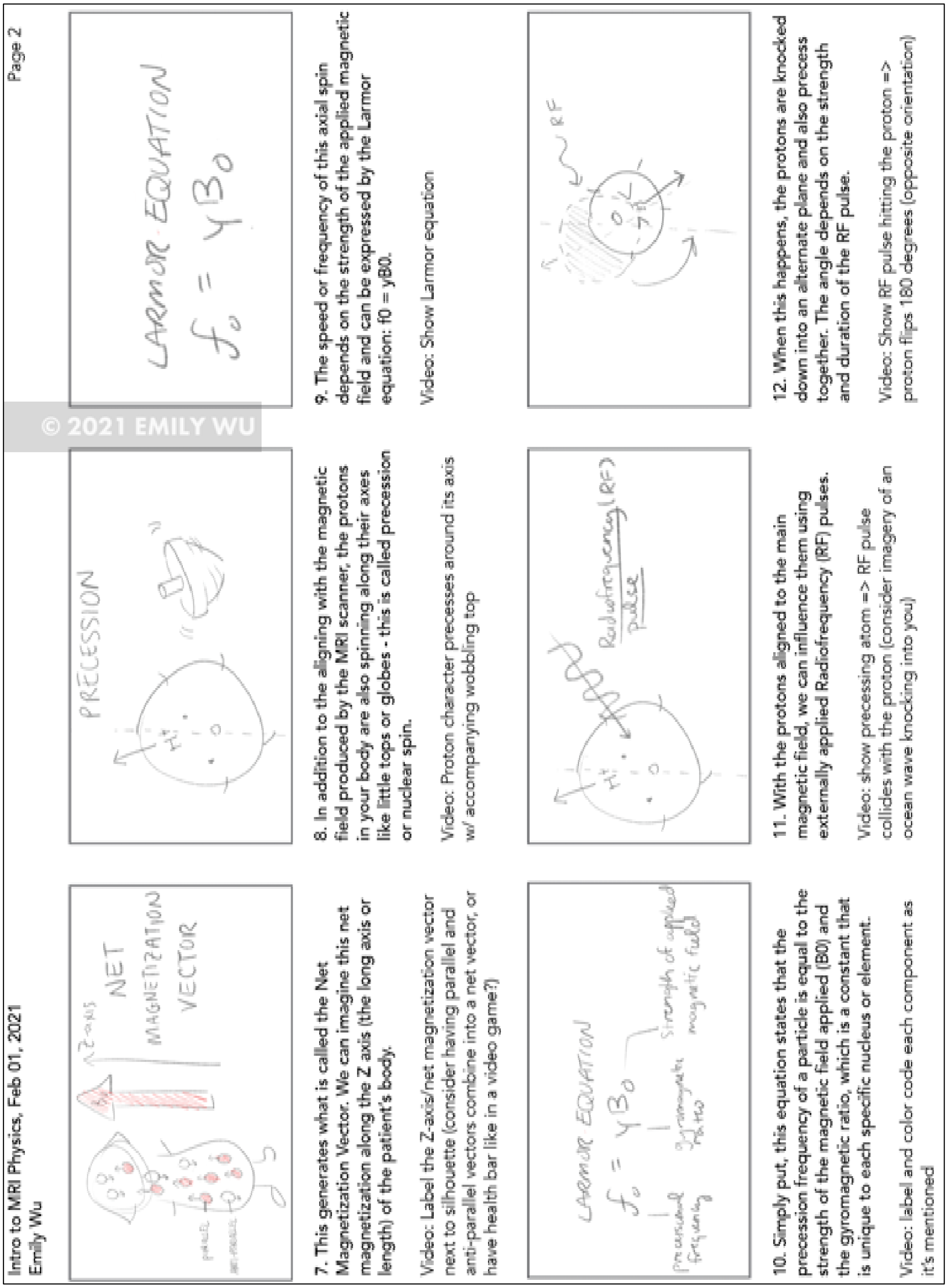


Figure 15. *Storyboard, page 2.*

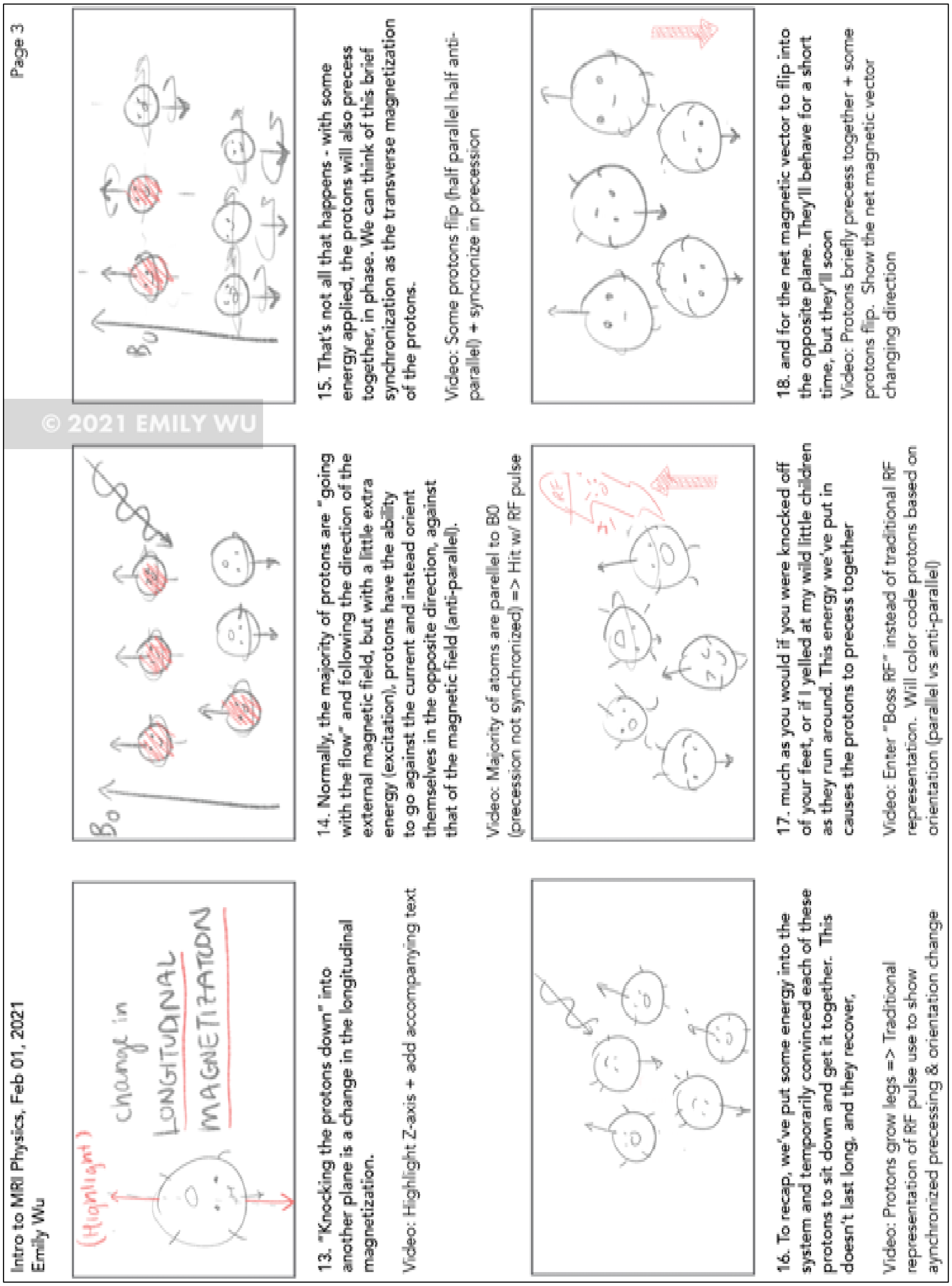


Figure 16. *Storyboard, page 3.*

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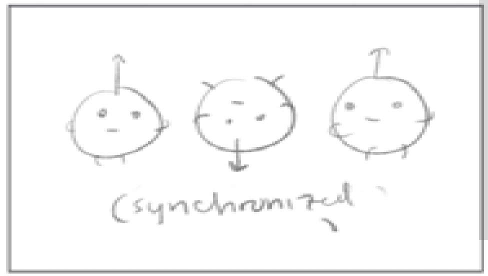
Page 4

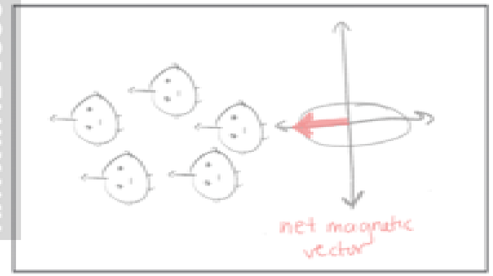
19. return my energy back to me as everything returns to its baseline state of disorder. Much like my children, these protons will recover, or return to their original state of orientation with the magnetic field and asynchronous precession.

Video: "Children" return to original activity.

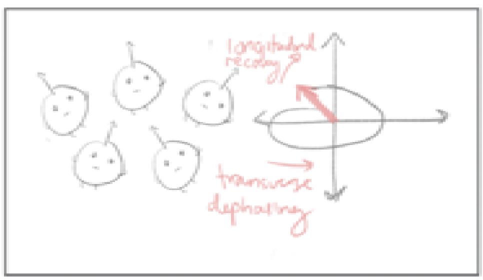


20 . Now that we've gone over what can happen when we administer an RF pulse, let's talk specifically about the pulses we'll use for a typical spin echo sequence.

Video: Show protons & "children" going through process side by side

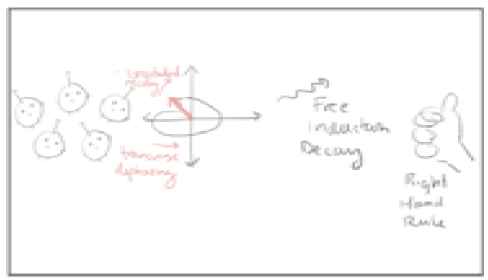


21. Remember, the "flip angle" induced by an RF pulse depends on the strength and duration of the pulse. The thing being "flipped" is the net magnetization vector. At the beginning of a standard spin echo sequence, we apply a 90 degree pulse - this means that after the RF pulse has been applied, the net magnetization vector is perpendicular to its original orientation. This orientation is achieved by eliminating longitudinal magnetization and generating a transverse magnetization vector by synchronizing proton precession.
Video: Animate vector/protons step by step

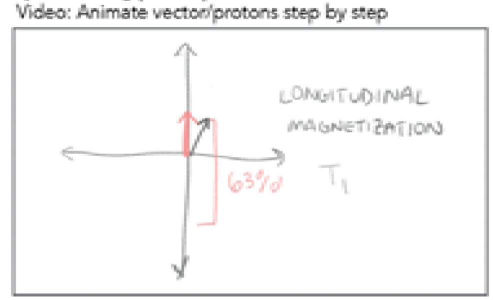


22. During recovery, longitudinal magnetization increases and transverse magnetization decreases (protons dephase) - this looks like a spiraling of the net magnetic vector along the z axis.

Video: Protons spread out (while spiraling) and precess separately (net magnetic vector spirals)



23. This spiraling of the net magnetization vector induces an electrical signal by a process called free induction decay, which is really just a throwback to the high school physics principle of inducing a current by rotating a magnetic field (search the depths of your mind for the "right hand rule").
Video: Energy wave release (free induction decay label) + Right hand rule cartoon + label.



24. A few additional terms to note: the recovery of the longitudinal magnetization of a proton occurs exponentially. The point at which 63% of the longitudinal magnetization has been recovered is called the T1 time.
Video: Net magnetization vector spirals. Stop and label at point at which 63% of original longitudinal has been recovered.

Figure 17. *Storyboard, page 4.*

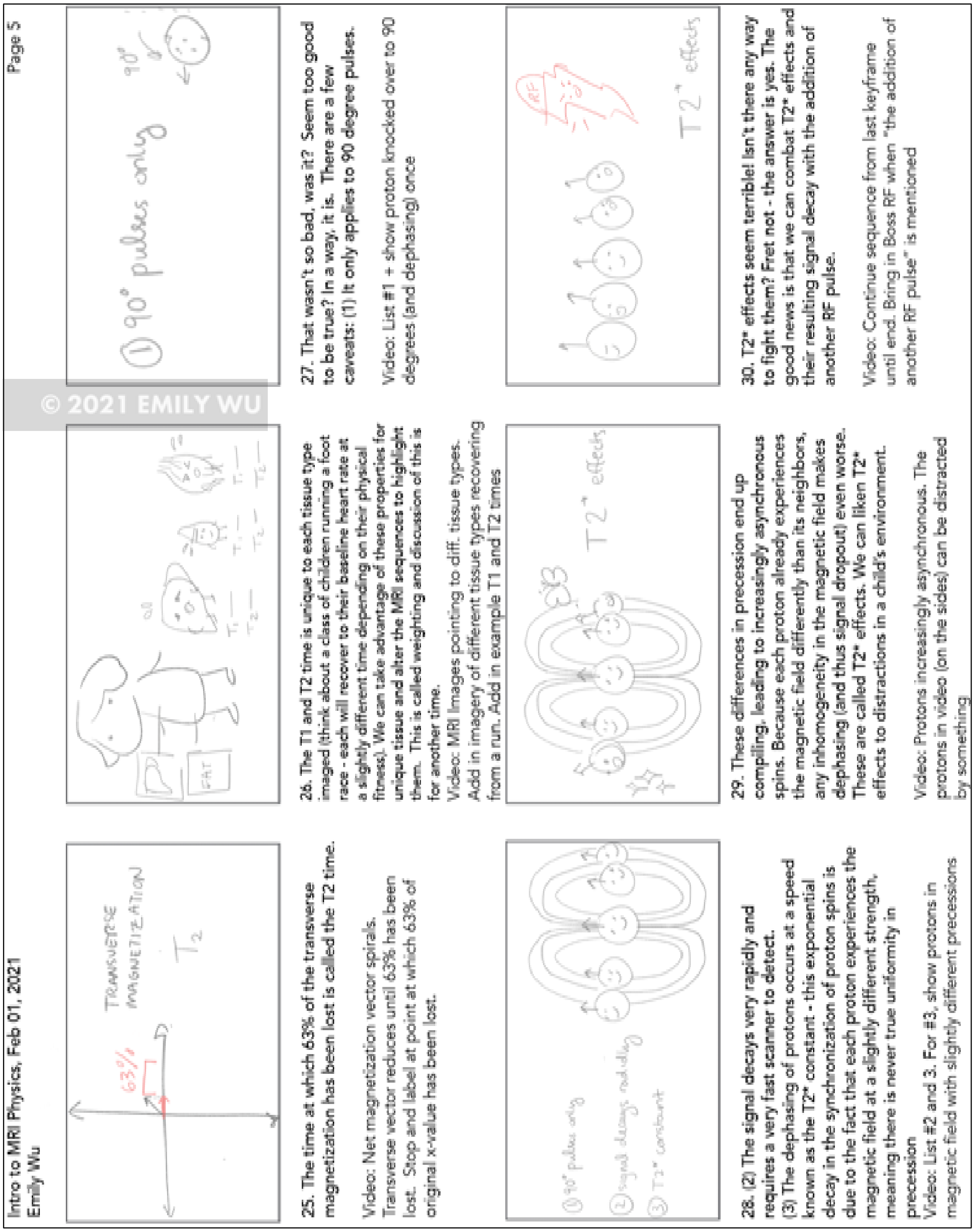


Figure 18. *Storyboard, page 5.*

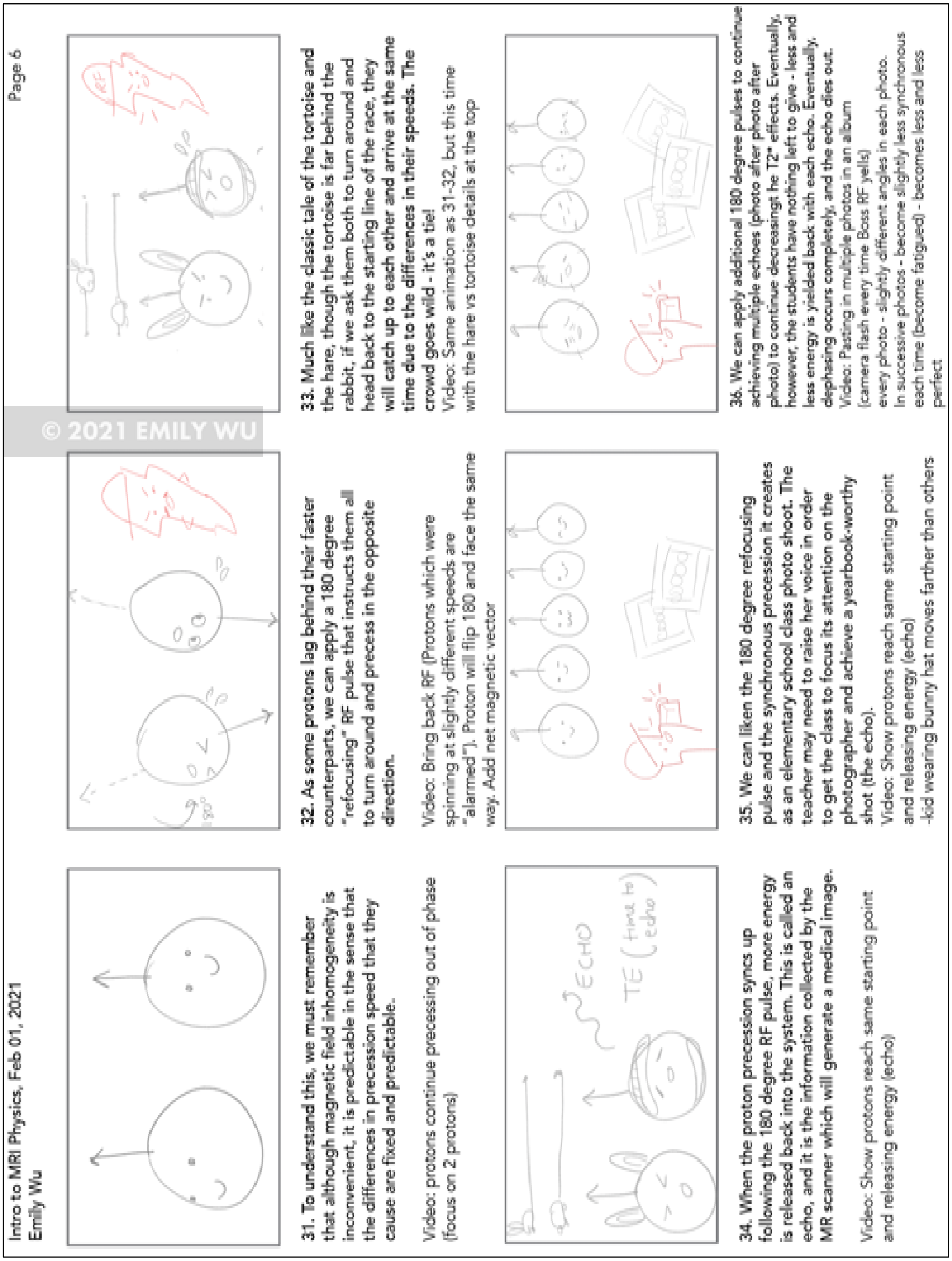


Figure 19. *Storyboard, page 6.*

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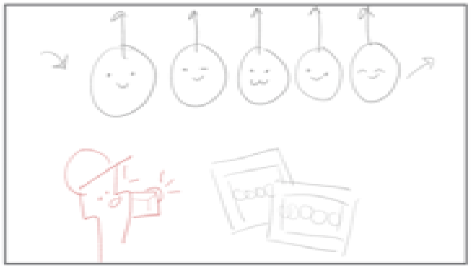
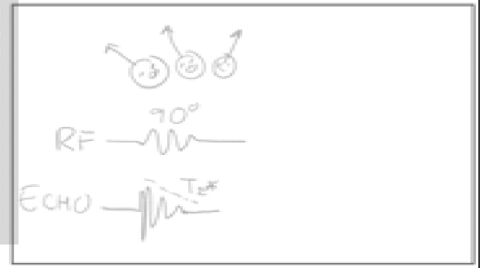


37. Once that happens, the sequence must be restarted again with another 90 degree pulse. Imaging in this manner is called Spin Echo or Fast Spin Echo imaging.

Video: RF pulse is like school photographer - each sequence - new group of students is hopping in.

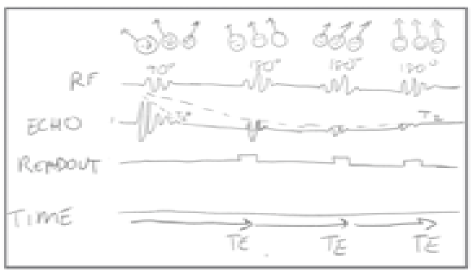
38. We can use universal diagrams to depict what happens with specific MR sequences. Let's use one to recap the basic fast spin echo sequence that we've discussed:
-Protons are aligned with the main magnetic field, B0, and are precessing randomly

Video: Recap with summary diagram. Show base of whole diagram (grayed out). Start by showing protons precessing in phase



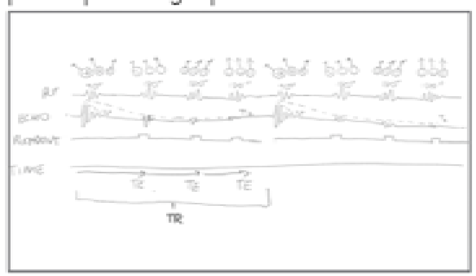
39. - A 90 degree RF pulse is applied, eliminating longitudinal magnetization and producing a transverse magnetization vector as protons precess in phase
- Longitudinal recovery and transverse decay occur, producing a signal via free induction decay, which is susceptible to T2* effects

Video: Protons knocked down 90 degrees => Dephase => Show RF and Echo in diagram



40. - A 180 degree refocusing pulse temporarily rephases proton precession, producing an echo which can be "Read-out" by the MR scanner. The moment that the echo is produced is called the TE, or time to echo.
- We can apply multiple refocusing pulses in an attempt to capture as many echoes as possible. The echoes become successively weaker until the signal dies out completely, and the sequence must be restarted.

Video: Show successive "shapshots" with 180 refocusing pulses w/ diagram reflecting events

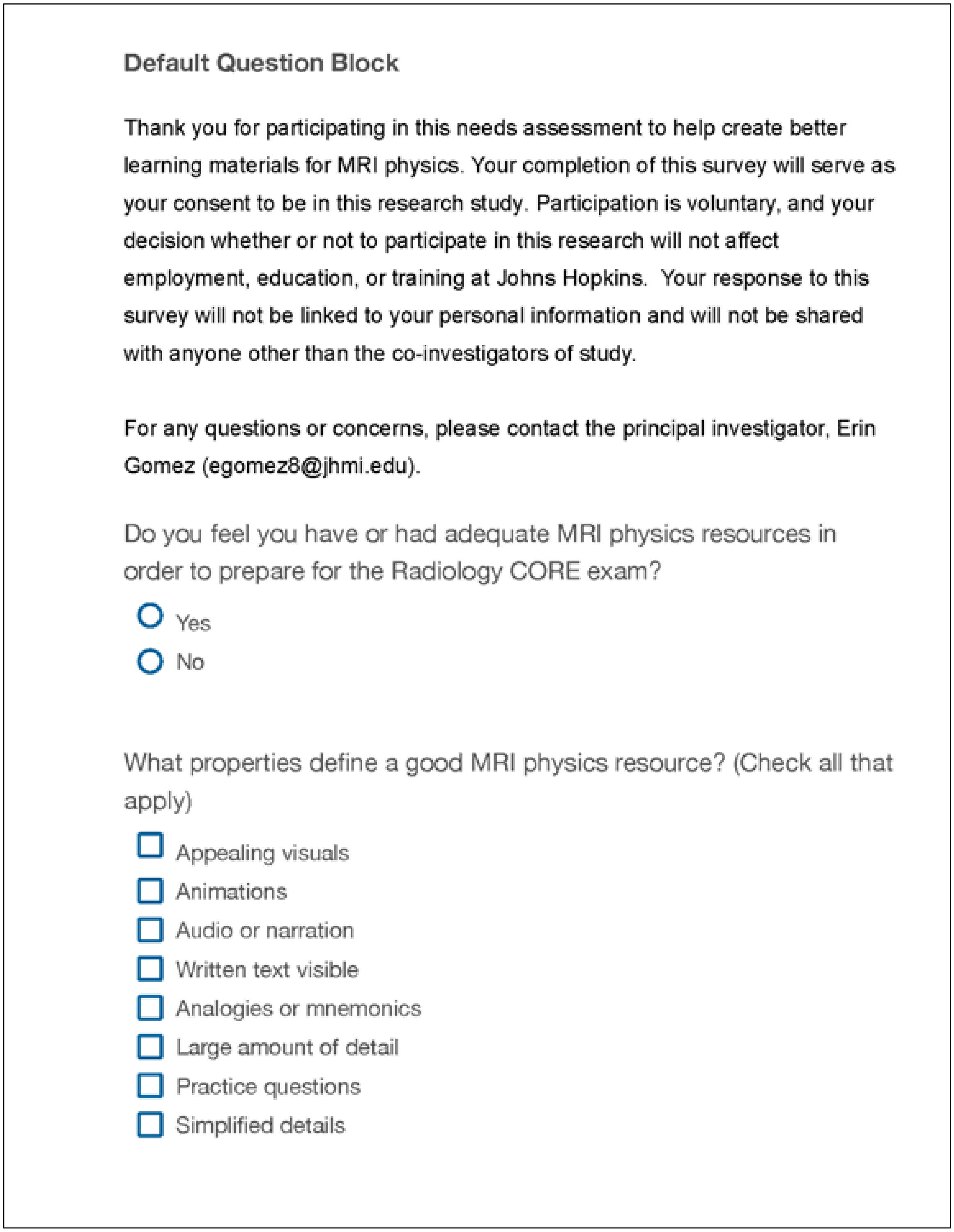


41. The time between the repetition of sequences is called the TR, or time to repetition.

Video: Repeat diagram/events with new sequence (highlight TR)

Figure 20. *Storyboard, page 7.*

APPENDIX C: Needs Assessment Qualtrics Module



Default Question Block

Thank you for participating in this needs assessment to help create better learning materials for MRI physics. Your completion of this survey will serve as your consent to be in this research study. Participation is voluntary, and your decision whether or not to participate in this research will not affect employment, education, or training at Johns Hopkins. Your response to this survey will not be linked to your personal information and will not be shared with anyone other than the co-investigators of study.

For any questions or concerns, please contact the principal investigator, Erin Gomez (egomez8@jhmi.edu).

Do you feel you have or had adequate MRI physics resources in order to prepare for the Radiology CORE exam?

- Yes
- No

What properties define a good MRI physics resource? (Check all that apply)

- Appealing visuals
- Animations
- Audio or narration
- Written text visible
- Analogies or mnemonics
- Large amount of detail
- Practice questions
- Simplified details

Figure 21. *Qualtrics module, page 1.*

☐ Other (please specify)

Please rate your agreement with the following statements.

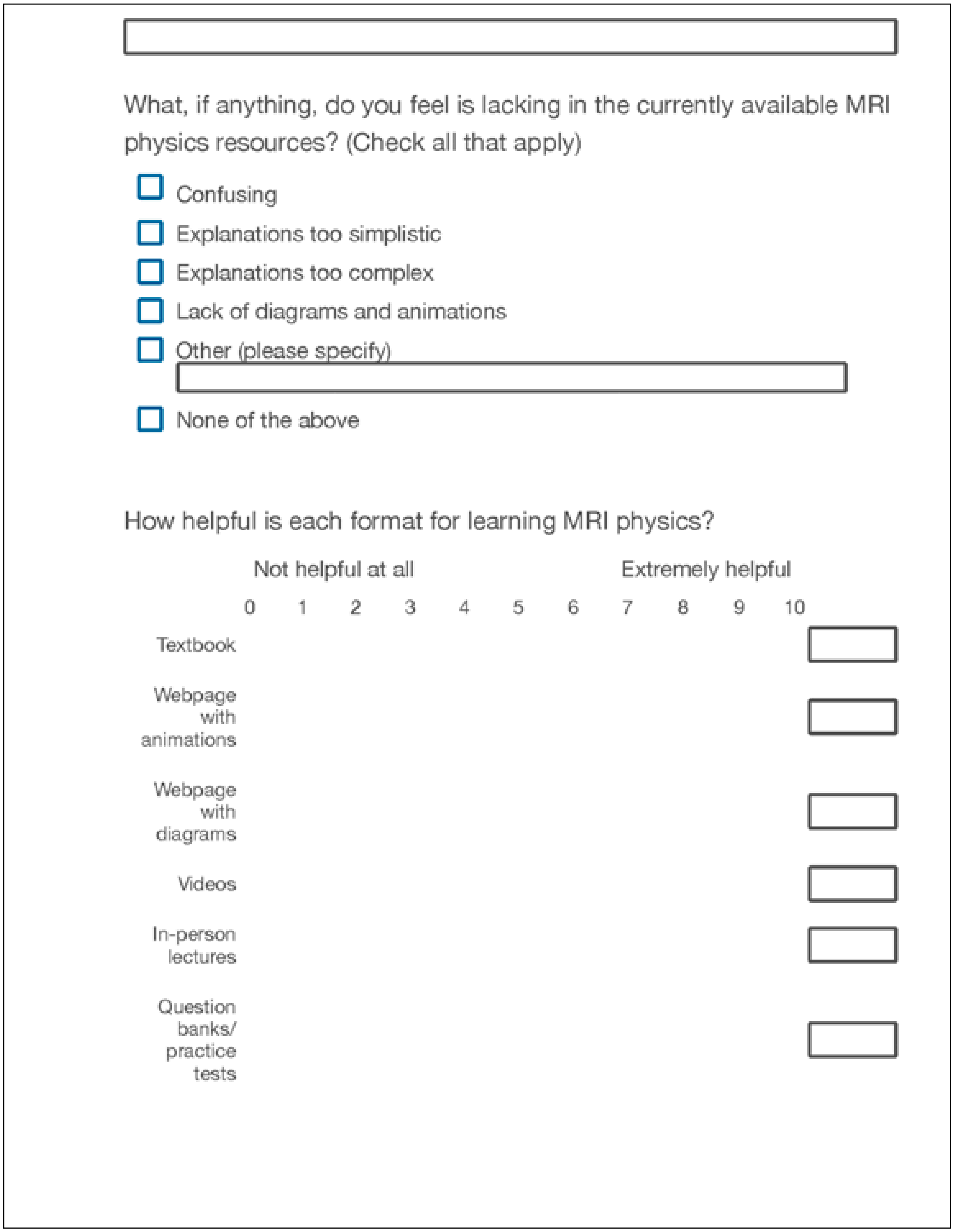
	Strongly disagree	Somewhat disagree	Neutral	Somewhat agree	Strongly agree
Currently available MRI physics resources are visually appealing.	○	○	○	○	○
I would benefit from more visuals to explain the fundamentals of MRI physics (e.g., interactive modules, 3D animations, or diagrams).	○	○	○	○	○

Which of the following concepts did you find the most challenging to learn?

- ○ Nuclear magnetic resonance
- ○ RF pulses and proton excitation/relaxation
- ○ Spatial encoding and MR gradients
- ○ K-space and k-space mapping
- ○ MR image resolution and contrast
- ○ None of the above

Optional: Explain why your answer to the above question was challenging.

Figure 22. *Qualtrics module, page 2.*



What, if anything, do you feel is lacking in the currently available MRI physics resources? (Check all that apply)

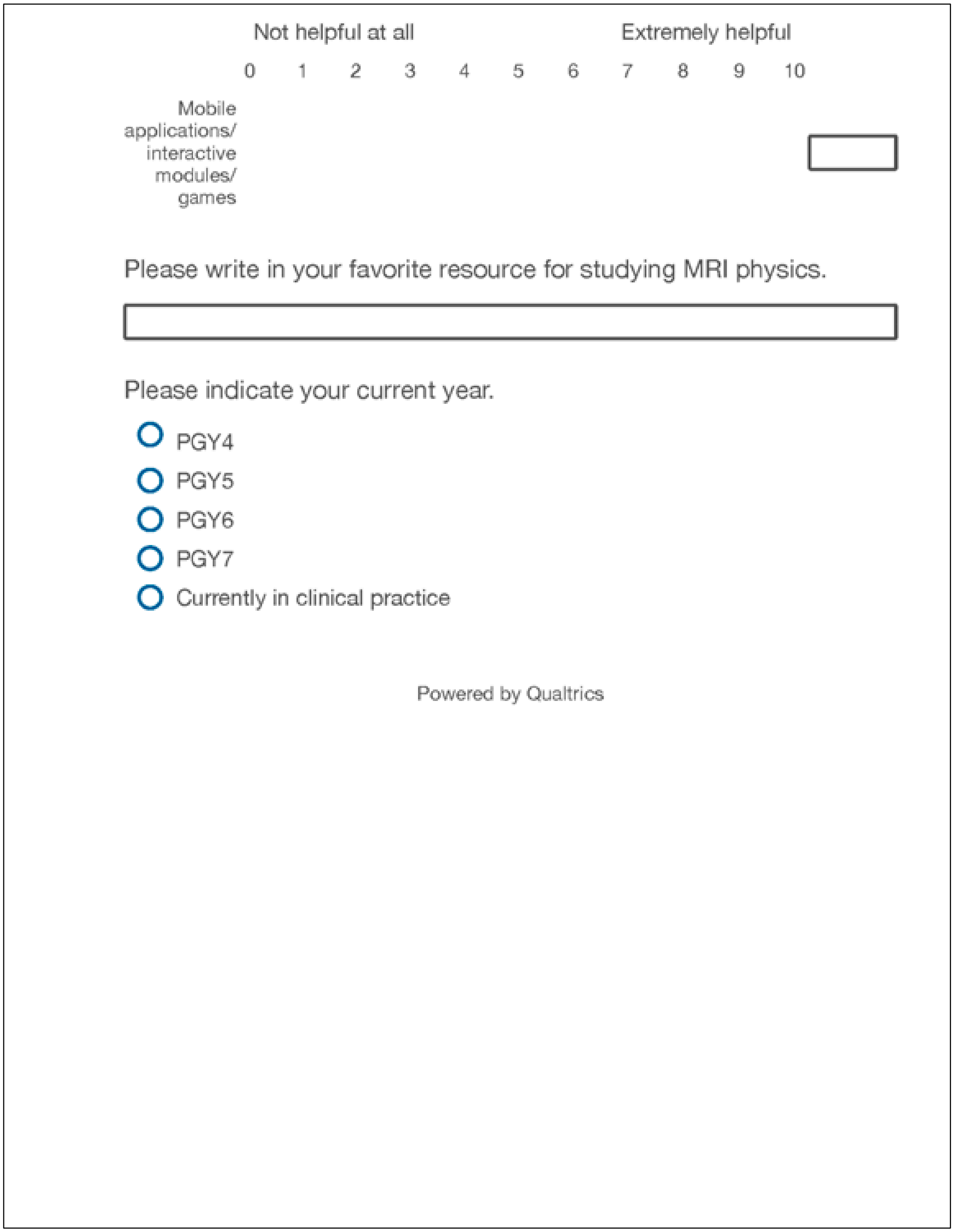
- Confusing
- Explanations too simplistic
- Explanations too complex
- Lack of diagrams and animations
- Other (please specify)
- None of the above

How helpful is each format for learning MRI physics?

Not helpful at all — Extremely helpful

	0	1	2	3	4	5	6	7	8	9	10
Textbook											
Webpage with animations											
Webpage with diagrams											
Videos											
In-person lectures											
Question banks/ practice tests											

Figure 23. *Qualtrics module, page 3.*



	Not helpful at all										Extremely helpful
	0	1	2	3	4	5	6	7	8	9	10
Mobile applications/ interactive modules/ games											

Please write in your favorite resource for studying MRI physics.

Please indicate your current year.

- PGY4
- PGY5
- PGY6
- PGY7
- Currently in clinical practice

Powered by Qualtrics

Figure 24. *Qualtrics module, page 4.*

References

American Board of Radiology. (2018). *Preparing for the Medical Physics Components of the ABR Core Examination* (Publication). https://www.theabr.org/wp-content/uploads/2018/08/IC_Study_Guide_Physics.pdf

"Best Radiology Programs." U.S. News & World Report, 2020. https://www.usnews.com/best-graduate-schools/top-medical-schools/radiology-rankings.

Bresolin, Linda, George S. Bisset, William R. Hendee, and Francis A. Kwakwa. "Methods and Resources for Physics Education in Radiology Residency Programs: Survey Results." *Radiology* 249, no. 2 (November 2008): 640–43. https://doi.org/10.1148/radiol.2483072004.

Casey, Brian. "Minnies 2015 Winners Showcase Radiology's Best." auntminnie.com, October 21, 2015. https://www.auntminnie.com/index.aspx?sec=log&URL=https%3a%2f%2fwww.auntminnie.com%2findex.aspx%3fsec%3dnws%26sub%3drad%26pag%3ddis%26ItemID%3d112159.

Hendee, William R. "Teaching Physics to Radiology Residents." *American Journal of Roentgenology* 192, no. 4 (April 2009): 855–58. https://doi.org/10.2214/ajr.08.2014.

Höffler, Tim N., and Detlev Leutner. "Instructional Animation versus Static Pictures: A Meta-Analysis." *Learning and Instruction* 17, no. 6 (2007): 722–38. https://doi.org/10.1016/j.learninstruc.2007.09.013.

Mayer, Richard E. "Cognitive Theory of Multimedia Learning." *The Cambridge Handbook of Multimedia Learning*, 2005, 31–48. https://doi.org/10.1017/cbo9780511816819.004.

Mayer, Richard E. "Multimedia Learning (2nd Ed.)," 2009. https://doi.org/10.1017/cbo9780511811678.

Mayer, Richard E., and Roxana Moreno. "Animation as an Aid to Multimedia Learning." *Educational Psychology Review* 14, no. 1 (March 2002): 87–99.

Milheim, William D. "How to Use Animation in Computer Assisted Learning." *British Journal of Educational Technology* 24, no. 3 (1993): 171–78. https://doi.org/10.1111/j.1467-8535.1993.tb00070.x.

Shetty, Anup S., Joseph R. Grajo, Summer Decker, Darel E. Heitkamp, Kristen K. DeStigter, Duane G. Mezwa, and Lori Deitte. "ABR Core Examination Preparation." *Academic Radiology* 22, no. 1 (January 2015): 121–29. https://doi.org/10.1016/j.acra.2014.07.026.

Thomas, Owolabi, and Oginni Israel. "Effectiveness of Animation and Multimedia Teaching on Students' Performance in Science Subjects." *British Journal of Education, Society & Behavioural Science* 4, no. 2 (January 2014): 201–10. https://doi.org/10.9734/bjesbs/2014/3340.

Tversky, Barbara, Julie Morrison, and Mireille Betrancourt. "Animation: Can It Facilitate?" *Int. J. Human-Computer Studies* 47, no. 4 (October 2002): 247–62. https://doi.org/doi:10.1006/ijhc.1017.

Vita

Growing up in the suburbs of Pittsburgh, Pennsylvania, Emily Wu spent a quiet childhood reading books and drawing fantastical creatures. Throughout high school, she mainly focused on the sciences while cultivating her passion for art in her free time. Eventually, she moved to St. Louis, Missouri, where she lived for five years, obtaining her B.A. in Biology and in Psychology from Washington University in St. Louis and working as an outpatient medical scribe while she applied for medical school. During her final year in St. Louis, she discovered the profession of medical illustration, which combined her interests in science, medicine, and art. Abandoning her pursuit of medical school, she instead moved to Baltimore, Maryland where she attended a classical atelier to hone her artistic skills for the next two years before diving into the field of medical illustration.

Emily is currently finishing her second year as a medical illustration graduate student at Johns Hopkins University School of Medicine. The Medical and Biological Illustration program was Emily's first foray into the world medical and scientific illustration and has been a life-changing experience. During her time in the program, Emily was supported by the William P. Didusch Scholarship and W.B. Saunders Scholarship and was a recipient of the Frank H. Netter, M.D Memorial Scholarship in her first year of study.

Emily will be receiving her MA in Medical and Biological Illustration in May of 2021. After graduation, she aims to continue educating others about their health and to inspire curiosity about the world through her illustrations and animations.